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THEORY AND USE OF THE PERIODOCRITE.*

By CHARLES F. MARVIN, Chief, U. S. Weather Bureau.

[Washington, D. C., Mar. 1, 1921.]

SYNOPSIS.

Periodocrite [1] is a word coined from Greek roots signifying a critic, a judge, a decider of periodicities, and is a name applied to a mathematical and graphic method or device which has been developed to aid in the conclusive separation of obscure and hidden cycles and periodicities possessing a real existence from those whose essential features are only such as would result from, and can be explained by, entirely chance combinations of the data employed.

The periodocrite does not disclose or discover the *length* of suspected periods or cycles. Other methods, such as the harmonic analysis, Schuster's periodogram, or any of the many methods which have been offered for this purpose must first be employed to ascertain the proper length of any suspected cycle.

Suggestions for clearness in terminology are offered; the elements of the theory are briefly presented, the significance of the results secured in applications to practical data are illustrated by examples, and methods of abridging certain mathematical computations are indicated.

The paper concludes with representations concerning the inherent characteristics of data, the limitations upon the use of the familiar least square methods in problems of meteorology, and some suggestions are offered for overcoming difficulties thus entailed.

INTRODUCTION AND TERMINOLOGY.

How can claims of periodicities in the succession of values of meteorological and like data be proved or disproved?

If a definite and conclusive answer to this important question were known, vast expenditures of time and labor on the part of many students might have been spared in the past and like efforts conserved in the future for more fruitful pursuits than one so alluring and baffling as the search for obscure and hidden cycles believed by many students to lie concealed in practically any body of meteorological and like data.

Science must furnish conclusive answers to the claims and questions with which students of periodicities are confronted and this paper is an effort to supply a few basic principles which may serve as part of a greatly needed solid foundation upon which any superstructure of periodic theories and claims may be successfully erected.

If what is offered does not suffice fully to segregate specious sequences from cyclical or periodic elements which have a physical *raison d'être*, nevertheless it may guide the reader in forming his own conclusions and aid the investigator to avoid wasted effort on studies which must necessarily lead only to fruitless or inconclusive results.

Our acceptance and approval of claims of periodicities which may be advanced is justified only when it has been demonstrated that the propositions involved can successfully run the gauntlet of tests and criteria such as presented herein.

As if to add the last acid test to whatever may emerge as real, rather than fortuitous, from all other tests, we must invoke the quality of *utility*. The value of a scientific truth is, of course, wholly independent of any numerical measure on which the fact depends. The parallax of a remote star may be vanishingly small but of vast importance. On the other hand, a periodicity which differs from a perfectly fortuitous sequence by only a very small margin may be an important scientific truth to demonstrate, but its practical value for forecasting or other purposes may be entirely inconsequential. I have indicated in an unpublished note how the forecasting value of knowledge of this character can be measured.

The ultimate goal of the student who seeks to formulate the laws of sequences of solar and terrestrial phenomena and correlations thereof must be to establish, first, the REALITY, second, the UTILITY of claims.

For the present purposes, statistical data may be put into two classes:

Class I is illustrated by observations which exhibit the diurnal and annual march of temperature and pressure, the seasonal variations in rainfall, the 11-year period in sunspots, and like features in terrestrial magnetism. Simple inspection of such data or graphs of it leaves no doubt as to its periodic features. Either aided or not by known laws defining the length of the periods, the major question in these cases is to fix the amplitude and elements of the period, or, in the more complex case presented by sunspots and magnetic phenomena, to ascertain the real length of the changeable period and the nature of its fluctuations.

Class II comprises many other cases in which no real period can be discerned by simple inspection, and this will be true also in cases of the data constituting Class I after steps have been taken, as is often done, to free the original material of any diurnal, annual, or other periodic features which can be evaluated with greater or less accuracy.

Terminology.—Differences unwittingly and unintentionally put upon the meaning of terms and language by the different parties discussing a given subject is too often the only ultimate basis for material differences of view. No other department of meteorology is more subject to this possibility than the question of cycles and periodicities. This is because the precise and exact terms and language of physical and mathematical harmonics are sometimes carelessly applied to features of data which crudely recur, when in fact the terms employed are quite inapplicable unless they carry different meanings from those ordinarily signified.

It is most important that the meaning of the language and terms of mathematical harmonics be kept pure and significant of certain definite things and not loosely applied to features of meteorological data which have only the slightest resemblance to a cycle, a period, a harmonic, or what not, as the case may be. It is needless to define here the mathematical terms of periodicities.

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*Presented before American Meteorological Society, Washington, April 20, 1921.

[1] Prof. C. F. Talman supplied this name from περίοδος, a period + κριτής a judge, decider, umpire, from κρίνω to separate, investigate, judge.

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This is abundantly done in the textbooks, and when used in a meteorological connection those terms should carry the customary meaning as exactly as possible. If this be done in a legitimate way, then readers will have a basis for the clear understanding of authors. Many of the recurrent features of weather phenomena which writers call or claim are periods, cycles, and the like, are little more than indefinite "*sequences.*"

The latter term seems particularly appropriate for meteorological application, and is offered for general use, defined somewhat as follows:

Sequence.—Any more or less complex succession of values of meteorological or other states, elements, etc., especially those which exhibit a tendency to cyclical or periodic recurrence. A portion of such sequences or a definite result derived therefrom which exhibits *marked periodic recurrence* of essential features may be properly called a *cycle* if somewhat complex, but when the form is definitely periodic and very simple, with essentially one maximum and one minimum value in the sequence, then the appropriate definitive designation, *periodic element,* is suggested. *Harmonic elements* or *harmonic components* are terms which should be used consistently to designate only those elements the inherent characteristics of which are sinusoidal, whereas periodic elements or components of weather sequences very often or nearly always are distinctly nonsinusoidal or nontrigonometric in any form, and the terminology should keep this inherent distinction clear.

The problem of the meteorologist and the forecaster seeking to extend the period of his forecasts far into the future, is to discover and formulate the *laws governing meteorological sequences,* if indeed those laws do not turn out to be indistinguishable from the laws of chance. This statement contains a very important truth deserving more recognition than it has received. Phenomena of chance are theoretically considered to be the outcome of the operation of a large number of independent influences or causes. Sequences of weather phenomena are also consequent to the operation of a large number of conspiring causes which in many particulars are quite independent, resulting in consecutive values whose laws of succession can be segregated from the laws of chance only with great difficulty and incompleteness. Progress in these studies has been hindered and delayed, no doubt, by the too hasty or too confident conclusion of many students that weather sequences can be *resolved* into cycles or *analyzed* into harmonic Fourier elements. The physical existence of an obscure cyclical component of data should be unequivocally proven before its reality is claimed, because errors of science advocated and diffused often on high authority tend to perpetuate themselves indefinitely, and their subsequent correction is exceedingly slow and difficult.

The Fourier series can REPRESENT *any* succession of variable values. It is utterly futile, however, in the great majority of cases, to push the application to more than an imperfect *representation.* Hourly values of temperature, for example, form a very nearly perfect periodic element. The sequence, however, is entirely nonharmonic. Its features are the outcome of chiefly two entirely independent processes: (1) An uninterrupted process of cooling which is subject to a large number of modifying influences such as cloudiness, winds, temperature, and nature of surface, etc. Cooling is always a losing operation, and this tendency to change as an elemental effect is always in one direction and is therefore absolutely nonharmonic, even nonperiodic. (2) The other control on diurnal temperature is the intermittent influence of solar heating, which begins at sunrise and is cut off at sunset, attaining various intensities at intermediate hours, depending on atmospheric transmissibility, etc. As an elemental effect, this also is absolutely nonharmonic because it is intermittent.

Of course other factors modify the hourly values of temperature, such as importation of warm or cold air from a distance, etc., but the diurnal march of temperature is cited as an excellent example of a *periodic element* in weather sequences which is entirely nonharmonic in its physical character. Accordingly, the harmonic analysis applied to such data is altogether meaningless except that the sum of the harmonic elements simply *represents* the original data.

On the other hand, the sequence of daily, weekly, or monthly values of mean temperature for a station or locality form a good example of an annual cycle whose features are found by both theory and observation to conform satisfactorily to a limited number of Fourier elements.

Sequences in values of pressure, humidity, cloudiness, precipitation, the departures of elements from average, and so-called normal conditions all quickly become very complex and nonharmonic. Resort to the use of devices and terminology of the harmonic analysis in the discussion of such data is more apt to mislead the student and confuse the reader than to disclose useful meteorological laws and principles.

It has seemed necessary to offer the foregoing discussion on terminology because the literature of the subject is often lacking in consistency and clearness, and the making of the distinctions and discriminations mentioned is necessary to an understanding of what follows

THE PERIODOCRITE.

It is assumed we have at hand a large number, N, o homogeneous values of any variant which is suspected to be characterized by one or more hidden cycles or periodic elements. The data may represent temperature, rainfall, sunspots, intensities of radiation, or what not, and it is assumed all *obvious* periodicities like the diurnal, annual, and other cycles have been eliminated by appropriate methods, also that the data have otherwise been brought into a homogeneous body of values of equal weight. Finally, it is assumed that a group or succession of p values of these data comprise a more or less complex cycle or periodicity which repeats itself over and over again. However, owing to the large accidental variations of the values of the variant, the cycle is hidden and can not be satisfactorily discerned from a careful inspection of the data.

The well-known method of evaluating or proving a periodicity in such a case consists in tabulating the data in rows and columns in a manner designed to *bring into the same columns data of the same suspected phase relations.* The accidental variations will thereby tend to average out, and the real features of the hidden periodicity will be exhibited by the sums and means of the phase columns. Emphasis is placed on the words in italics because in carrying out a tabulation in rows and columns it is equally possible to place in each of the several columns the same phase values of the data *when the length of the period is variable as when it is constant.* Attention to this point is necessary if we are to deal properly with periodicities, the length of which vary systematically and progressively as claimed by some investigators. The

only difficulty introduced by the variability in the length of the period is the added labor of computation it entails.

Let a tabulation of any portion or all of a given body of data in p phase columns and n rows be indicated by letters as below, and for brevity let any group like this be designated a "*tabulation*":

A periodicity tabulation.

Number of cycles (n).	Phase values.							
	0	1	2	3	......	......	......	$p-1$
1	a_0	a_1	a_2	a_3	......	......	......	a_p-1
2	b_0	b_1	b_2	b_3	......	......	......	b_p-1
3	c_0	c_1	c_2	c_3	......	......	......	c_p-1
....	......	......	......	......	......	......	......	......
....	......	......	......	......	......	......	......	......
n	n_0	n_1	n_2	n_3	......	......	......	n_p-1
Sums	S_0	S_1	S_2	S_3	......	......	......	S_p-1
Means	m_0	m_1	m_2	m_3	......	......	......	m_p-1

The whole body of homogeneous data available is supposed to be indefinitely large, permitting of one or several relatively large "*tabulations*" of independent data.

Now, only one of two results is possible with reference to the sums S or the means m derived from adequate data.

(1) The sums, as likewise the means, will be constants—that is, differences will be small and negligible, and therefore no period is indicated, or

(2) The differences in the successive values of S or m will be of material magnitude and may possibly signify a cycle.

Experience with meteorological and like data teaches us that when n in a *tabulation* is very small, say 3 or 4, the variations in the values of m will be very large. In general, a mean of 4 sets of values will show only about one-half, and of 9 sets often only about one-third as much range of variation as exhibited by any one of the single sets. It is also generally found that when all obvious periodicities have been eliminated, the means of a *tabulation* show less and less differences among themselves as the value of n increases. These are relations which we know correspond entirely to the requirements of chance.

Accordingly, the question at once arises: Are the variations found in the values of m_0, m_1, m_2, etc., in any limited *tabulation* in any degree different from variations which would be found in values computed from entirely chance combinations of the same body of data? We may assume, for example, that all the values constituting the original observations are completely mixed up in a bowl and that any specified *tabulation* is made up entirely from pure chance drawings. The body of data thus secured will differ from the actual observation in only one particular, namely, *the order of succession* of the values. In all other features, as the mean, the mode, the median, the standard deviation, etc., the whole distribution of the chance drawings will be identical with like elements of the original observations which will differ only in the order of succession of values. We may well ask, therefore, how will values of m_0, m_1, etc., for actual observations differ from similar values derived entirely from chance drawings from the same body of numbers?

The search for the answer to this question led to the development of the periodocrite. It is a method and a graphic device which serves not only to segregate real from accidental periodicities, but with an adequate amount of data will afford a very satisfactory index number which shows the *realness* of the periodicity.

Theory.—The theory of the periodocrite is briefly developed as follows:

Let $\sigma_0 = \pm\sqrt{\frac{\Sigma V^2_N}{N}}$ = the standard deviation of the whole body of data, in which ΣV^2_N designates the sum of the squares of the departures, and N the total number of observations. The subscripts attached here and elsewhere to the symbol V^2 designate the particular group of data from which the sum of the squares of the departures is derived, in this case the whole body of data N. It is assumed σ is computed by forming the frequency distribution in the usual manner, and if the distribution is distinctly unsymmetrical, that fact should be ascertained and duly considered, together with any features of abnormality which may affect the data and which probably can not be easily removed.

Perfect fortuity.—We shall first consider the case of perfect fortuity. We must necessarily assume that in any *tabulation* of a portion of the whole data, the values in the portion, n rows and p columns, for example, or np values in all, are representative of the whole body of data. Of course the failure to satisfy this requirement always occurs in problems of chance, and it simply causes minor deviations from theory which are generally recognized andunderstood. On the assumption made, then, in the long run we may write:

$$\sigma_{np} = \pm\sqrt{\frac{\Sigma V^2_{np}}{np}} = \pm\sqrt{\frac{np\frac{\Sigma V^2_N}{N}}{np}} = \sigma_0$$

Also, if σ_n is the standard deviation of the p mean phase values of a *tabulation*, then

$$\sigma_n = \pm\sqrt{\frac{p\Sigma V^2_m}{np}} = \pm\sqrt{\frac{\Sigma V^2_s}{np}} = \pm\sqrt{\frac{\Sigma V^2_m}{n}}$$

Now if chance is the only factor which controls the results brought out in a *tabulation*, then from the principles of least squares we must have

$$\sigma_n = \frac{\sigma_0}{\sqrt{n}} \text{ from which } \frac{\sigma_n}{\sigma_0} = \frac{1}{\sqrt{n}} \qquad \text{-------(1)}$$

Let y = the ratio $\frac{\sigma_n}{\sigma_0}$ which we may regard as a coefficient of variation.

Also let $\frac{1}{\sqrt{n}} = x$. Hence from (1)

$$y = x \qquad \text{-------(2)},$$

which is the equation of a straight line through the origin of coordinates at an angle of 45° to the axes. From the derivation of its equation such a line represents the results of perfectly fortuitous combinations of the data employed. (See fig. 1.)

Since n is any integer from 1 to + infinity, the values of x lie between $x=0$ and $x=+1$. Likewise, the values of y range between $y=0$, and $y=+1$, because for perfectly fortuitous control when $n=+$infinity $\sigma_n=0$, hence $y=0$ and when $n=1$, σ_n *on the average* $=\sigma_0$. ˙. $y=1$.

The application of the foregoing to actual observational data is very simple. Having computed the standard deviation σ_0 for all the data, find mean phase values m_0, m_1 ..... for one or several tabulations. Then deduce values of x and y as explained. If these are equal, or nearly so, then the variations in the values of m_0, m_1, m_2, etc., are no greater than those due entirely to chance, and

at least in so far as the *amplitude* of variations is concerned no claims of periodicity are justified.

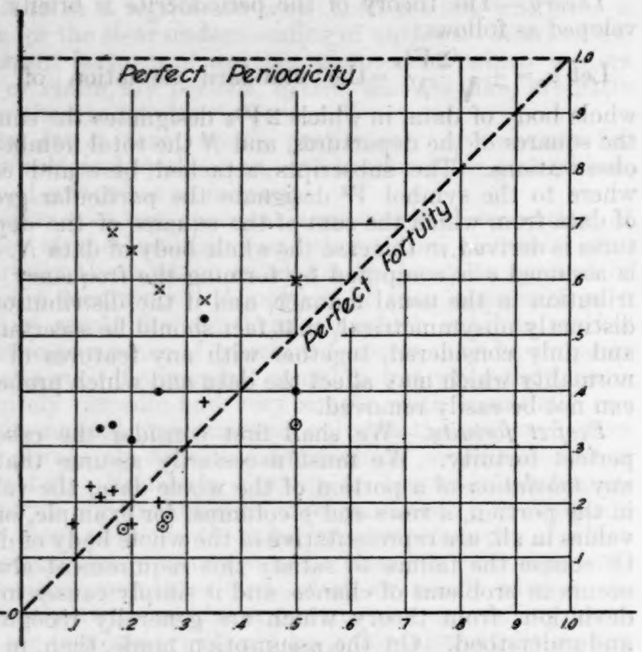

FIG. 1.—Rainfall periodocrite. Star: Annual cycle five stations in Iowa, 36-year record. Heavy dots: Annual cycle Washington rainfall, 50-year record. Crosses: Annual cycle Boston, Mass., 103-year record, very feebly defined. Circles: A 15-month sequence, Iowa rainfall. Other sequences, 15 months, 16 months, one-ninth the variable sunspot period, like the circles, all fall in the class of perfect fortuity.

Perfect periodicity.—Let us consider data which exhibits perfectly cyclical succession of values, as for example consecutive values of the average hourly temperatures repeating the sequence over and over again. Of course the periodic feature would be perfectly obvious in such a case and there would be no need to resort to analytical demonstrations to establish a periodicity, however the case aids in developing the theory of the periodocrite.

It is known that σ_0 is entirely independent of any question of the order of succession of the data. However, if p values in sequence constitute a complete cycle, then because the cycle is perfect a *tabulation* of np observations will give the same phase values of m_0, m_1, m_2, etc., whatever the value of n $\therefore$ $\sigma_n = \text{constant} = \sigma_0$ for perfect periodicity and $\therefore$ $y = \frac{\sigma_0}{\sigma_0} = \text{constant} = 1$ ....(3), which is the equation of a line parallel to the axis of X at distance 1 and is a line of perfect periodicity.

From the foregoing we see in general that to test a periodicity it suffices to form one or more *tabulations* as explained and compute values of x and y for one or more groups of data. When y is substantially and consistently greater than x a real periodicity is indicated of greater or less amplitude. If x and y are nearly equal, especially y smaller than x, the amplitude of the periodic variations is less or no greater than that due wholly to chance. In the face of such a result, the probability of the cycle being real is very small or nil. An entirely new body of data may give a like range of values of phases, but the order of succession may be quite different. If, however, the order and features of succession of the phase values should prove to remain sensibly invariable even while x and y remain nearly equal for different *tabulations* of independent data, then the conclusion must be that a periodicity exists of amplitude no greater than chance alone will produce, and the period tends to vanish as the length of record increases.

It will be noticed that theoretically y can not exceed unity; however, when n is large y may become several times larger than x. This shows strongly marked periodicity, but in all such cases inspection alone establishes the same fact, and the calculation of x and y simply serve to express in numerical terms the proportionate effects of periodic control as compared with chance represented by x.

SUMMARY OF APPLICATIONS.

The principle of the periodocrite has been applied to a short study of rainfall in annual and approximate 15-month cycles, both fixed and variable in length. The results are shown partly in figure 2. Only the annual cycles show any real existence. Even this is very feeble at Boston, Mass., for a long record of 103 years. All other cases examined show a variation over the cycle just such as the laws of chance would lead us to expect, that is no period except the annual one has been found.

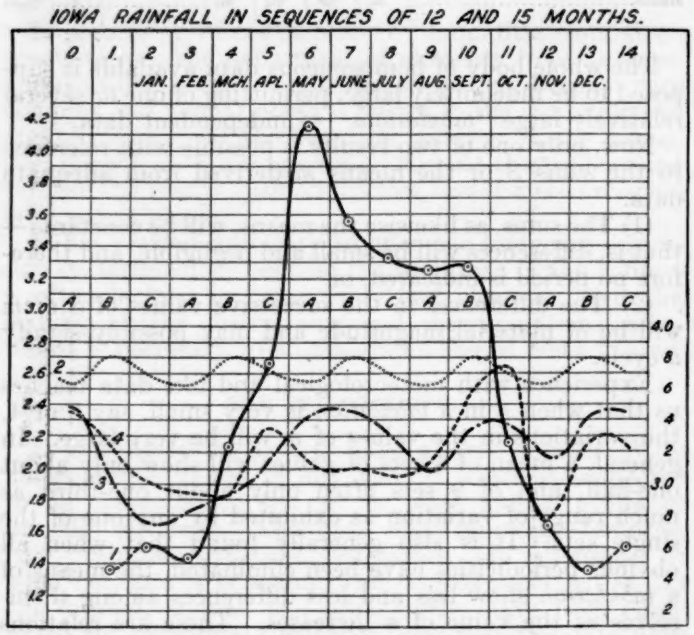

FIG. 2.—(1) Annual cycle, 36 years. (2) Effect of distributing the annual cycle through a 15-months sequence. (3) Actual 15-month cycle after eliminating annual cycle by ratios. (4) Same cycle, secured by fortuitous drawings from 36 years of monthly ratios.

ABRIDGED METHODS OF COMPUTATION.

Investigations of periodicities by the methods indicated in the foregoing require many calculations of σ, the standard deviation of the data. The quantity σ appears in the theory simply as a measure or index of the diversity or amount of variation either in the whole body of data or of certain portions thereof supposed to constitute a cycle or periodic element. Some other measure of variation, such for example as the average departure from the mean taken without regard to sign, will serve the same purpose and with nearly the same accuracy.[2] In fact, this index of diversity, $V_n = \frac{\Sigma V}{n}$ of any group of values, as of S_0, S_1, S_2, etc., or of m_0, m_1, m_2, etc in a *periodicity tabulation*, is quite as dependable for present purposes as $\sigma_n = \pm\sqrt{\frac{\Sigma V^2}{n}}$ or a value of the probab levariation, $E_n = \pm .6745\sqrt{\frac{\Sigma V^2}{n-1}}$ because in any one of these cases

[2] Davenport: C. B. Statistical methods with reference to biological investigations. New York, 1914. p. 16.

we are compelled to measure the variation of relatively small groups of numbers. As a random sample of the whole body of data, such groups are not representative. As a general rule, a small portion of the data will tend to show *less variation* than the whole body of data, because the very large departures which are due to occur infrequently are not likely to be found in a small sample taken at random. On the other hand, when such extremes do occur the variation for the small group then appears to be too great. All these considerations fully justify using simply $V_n = \pm\frac{\Sigma V}{n}$ as a measure of variation. The calculation of $\frac{\Sigma V}{n}$ is much easier than the quantity $\frac{\Sigma V^2}{n}$ and there is indicated below a quick method of computing ΣV without even forming the individual values of departures V. In this connection it is shown in the textbooks on least squares [3] that there is a direct relation between ΣV and the standard deviation σ. Thus it is shown that the probable error of a single observation is

$$r = \frac{.8453\ \Sigma V}{\sqrt{n(n-1)}}$$

From this it is easy to show that

$$\frac{\Sigma V}{n} = .7979\ \sigma_n \qquad (4)$$

This relation is of much practical importance and is used in the present connection in the following manner:

To enter upon any rational study of any independent body of data a first important step is to reduce the data to as homogeneous and as elemental a state of values of equal weight as possible. Then form a frequency classification and compute the standard deviation. We designate this value

$$\sigma_o = \pm\sqrt{\frac{\Sigma V^2{}_N}{N}}$$

From (4) we easily obtain

$$V_o = \frac{\Sigma V_N}{N} = .7979\ \sigma_o$$

It is seen, therefore, to be good practice to compute the standard deviation directly from the *whole body of data* and from this to evaluate $\frac{\Sigma V}{N}$ indirectly, because this value is subsequently needed for comparative purpose with other values of $\frac{\Sigma V}{n}$ derived by abridged methods of computation, as follows:

Let $a_1, a_2, a_3, a_4 \ldots . a_n$ be any group of values for which the arithmetical sum of the departures from the mean is desired.

Tabulating the usual operation of effecting such a calculation we get a table as follows in which the t positive and u negative departures are set out in different columns in which b_1, b_4, etc., indicates values of a which are greater than the mean and c_2, c_3, etc., values of a equal to or less than the mean.

[3] M. Merriman: Method of Least Squares. John Wiley & Sons. 1915. P. 92.

Tabulation of departures from mean.

Values.	Departures.	
	Positive.	Negative.
a_1	$b_1 - M \mp \frac{r}{n}$.	
a_2		$c_2 - M \mp \frac{r}{n}$.
a_3		$c_3 - M \mp \frac{r}{n}$.
a_4	$b_4 - M \mp \frac{r}{n}$.	
a_n		$c_n - M \mp \frac{r}{n}$.
Sums Σa	$\Sigma b - tM \mp \frac{r}{n}t$.	$\Sigma c - uM \mp \frac{r}{n}u$.

Mean $= \frac{\Sigma a}{n} = M \pm \frac{r}{n}$ in which r is a remainder in division which may be equal to but is generally less than $\frac{n}{2}$ and is rejected.

Now, from the law of the mean the algebraic sum of the departures $=0$,

$$\therefore \Sigma b - tM \mp \frac{r}{n}t + \Sigma c - uM \mp \frac{r}{n}u = 0 \qquad (4)$$

Let $\Sigma b - tM = B$ and $\Sigma c - uM = -C$.

$$\therefore B - C \mp \frac{r}{n}(t+u) = 0 \qquad (5)$$

Since $t+u=n$, $B-C=\pm r$, an equation which checks the accuracy of calculations when B and C are calculated separately.

Changing the signs of the quantities composing the negative departures in equation (4) and substituting B and C, we get for the arithmetical sum of departures,

$$\Sigma V = B + C \mp \frac{r}{n}(u-t)$$

which gives rigorously the sum of departures. Since $\frac{n}{2}$ is a maximum possible value of r and since $(u-t)$ tends to be zero or only small integral numbers, the term $\frac{r}{n}(u-t)$ is a small corrective term which can in general be wholly neglected. $\therefore$

$$\Sigma V = B + C$$

The practical meaning of all this may be stated in a simple rule for computing any values of ΣV, thus:

If not already known, compute the mean M of all the values, noting the amount of any discarded remainder r. Form the sum of all the values of the variant which are *greater* than the mean. Let the number be t. Subtract from the sum, t times the value of the mean. The difference is the sum of the positive departures, B. The sum of the negative departures is $C = B \mp r . \therefore \Sigma V = 2B \mp r$.

If desired, the work can be checked by computing C independently from the sum of the values of *a equal to or less* than the mean. It will be noted for check purposes we also have the relation

$$C = \Sigma a - \Sigma b - uM$$

Formulae similar to the foregoing could be developed for accomplishing the same results by the use of some arbitrary number R instead of the mean M. It is believed the abridgment of the work secured by use of the mean would be lost in the more complex calculations required if an arbitrary number is used.

A single example illustrates the comparative simplicity of this method of computing the mean departure of the results of a *tabulation*. The data are the monthly sums of a 16-year record of rainfall. We get the mean monthly departure without computing either the departures or the monthly means and the result is almost rigorously accurate—that is, fractional excesses are rejected only at the end and are a minimum. The tabulation in figure 3 shows the work as carried out on a listing machine which greatly facilitates the computation.

ABRIDGED CALCULATION OF MEAN DEPARTURE

	Monthly Sums	Sums greater than Mean	
	27.32	44.51	
	22.57	70.22	
	33.56	53.25	$6 = t = u$
	44.51	52.81	
	70.22	51.81	
$n = 12$	53.25	47.62	
	52.81	$320.22 = \Sigma b$	
	51.81	$243.24 = tM = uM$	
	47.62	$+76.98 = B$	
	33.94	$-77.01 = C$	Diff $= -3 = r$
	25.28	$153.99 = \Sigma V$	
	23.56		

Sum $= \Sigma a = 486.45$

Mean $= M = 40.54$

$r = -3$

Σa repeated $= 486.45$ $\quad n = 12$

Σb " $= 320.22$ $\quad p = 16$

Diff. $= \Sigma c = 166.23$ $\quad np = 192$

$uM = 243.24$

Diff. $= C = -77.01$

$$V_n = \frac{\Sigma V}{np} = \pm .802$$

FIG. 3.

The mean departure, however, computed, is probably the best and most easily evaluated measure or index of variation we can employ when such a measure is needed. This is especially the case when there are several secondary maxima and minima in a small group of values.

Of course, when periodicities are very elemental and closely harmonic in character, the *amplitude* of the various harmonic elements of a complex cycle is an all-sufficient index. On the other hand, when we are dealing with a complex cycle with many inflexions, little significance attaches to the extreme range between the maximum and the minimum values as an index of variation.

THE INHERENT CHARACTERISTICS OF DATA.

All detailed records of meteorological conditions and many like phenomena of solar and terrestrial activities are of an exceedingly complex character.

Real progress in the study and analysis of such data and interrelations thereof is greatly promoted by a recognition of its inherent characteristics and attention to questions of comparability, homogeneity, uniform weight of values, period of time covered, and other such factors.

It is impossible to discuss these questions exhaustively in this note, and attention will be directed to only the following characteristics which are of special significance in the present connection:

(1) Variation or diversity of similar values.
(2) Order of succession and obvious periodicities.
(3) Frequency distribution:
  (a) Elemental.
  (b) Composite.
  (c) Symmetrical, Gaussian and non-Gaussian.
  (d) Skew.

(1) *The variation or the diversity* among a considerable number of assumed similar values of any meteorological element is of great importance when various combinations of values are made and conclusions deduced from the numerical results secured. Every student of the subject knows that so-called normals from short records are good or poor, depending upon how much variation there is in the individual values. Long records, that is, a large number of individual values are necessary to fix normals of tempertaure and rainfall which in general show great variations, whereas shorter records suffice to fix normals of elements like pressure, which exhibits smaller variations. The same elements show systematically much greater variation in one section of the country than in another. Also, during certain months or seasons the variations are greater than in others. These considerations which guide us in fixing our degree of confidence in the values of important *normals* are just as applicable to the averages of a given number of observations for whatever purpose they may be combined as for normals, and thus it follows that in all careful investigations of data *the diversity of the individual values is an inherent characteristic of much importance which must be properly evaluated and reckoned with.* The methods of doing this by proper allowance for strong and weak observational values, or by weights and otherwise, are so fully covered in the textbooks and generally practiced by students in the more exact sciences, that it is needless to go into such details here. Few students of physical meteorology appear to realize the splendid opportunity the enormous body of meteorological statistics offers for a higher order of statistical analysis and discussion than is frequently practiced. The object of the present effort is to secure attention to these important details of investigation and research.

(2) *Order of succession and obvious periodicities.*—The fundamental feature which identifies a periodicity *is the orderly recurrent succession over and over again of identical phase values.* Elastic vibrations and many like physical phenomena exhibit very perfect periodicity even when the amplitude is very, very small. In meteorology and the inexact sciences, examples of periodicity like the diurnal and annual changes in values of temperature, pressure, rainfall, etc., may also be very definite. In these cases, the *length* of the period is invariable and fixed by astronomical causes and relations. All such periodicities in general are well defined and perfectly obvious by mere inspection and in the majority of cases the amplitude of the periodic features is relatively large.

In cases like the succession of HIGHS and LOWS moving eastward in the extratropical latitudes, the interval between events is, very roughly, three to five days, but is extremely variable and at times there seems to be complete interruption or suspension of the orderly succession of events which, however, are resumed again after a

short time. These secondary features of the major phenomena of the general circulation of the atmosphere are attended by a whole train of characteristic changes in the values of pressure, temperature, sunshine, cloudiness, precipitation, winds, etc., all of which recur in sequences of highly irregular length and amplitude.

If we think in units of months, years, etc., obscure and indefinite sequences of the same irregular type and character as just described, all tending to semicyclical recurrence, are marked features of any long record which may be investigated.

Figure 4 is fully representative of practically any body of data which may be presented. A very simple change of scale and interval of time between successive values suffices to adapt the diagrams to become representative of a great many records which may be subjects of investigation.

One of the greatest problems in physical meteorology is to formulate bona fide laws of sequence of the semicyclical succession of values such as have just been discussed. Indeed, the problem is broadly general in many branches of the inexact sciences. Many fragmentary solutions or discoveries of alleged cycles have been offered, as a cycle of seven or eight years in temperature or the Brückner cycle of 35 years. An 11-year cyclical correlation of small percentage between tropical temperatures and sunspots is hesitatingly conceded to be of possible reality. Searching criticisms of such claims weakens rather than strenghtens their foundations of proof. In a last analysis the element of pure chance is such a large factor of domination of the events claimed, or, stating the matter in other words, the margin of reality over purely fortuitous recurrence is so small that such claims have no practical forecasting value. No useful margin of successful verification is possible. In the face of such facts one is puzzled to know how much may be accepted as a matter of physical reality and how much should be rejected as only the operations of chance.

Progress in the study of obscure periodicities requires:

(1) That the reality of the results claimed be established as far as possible by the use of more or less rigorous and analytical methods rather than by resort to arbitrary graphical methods often practiced and which too often

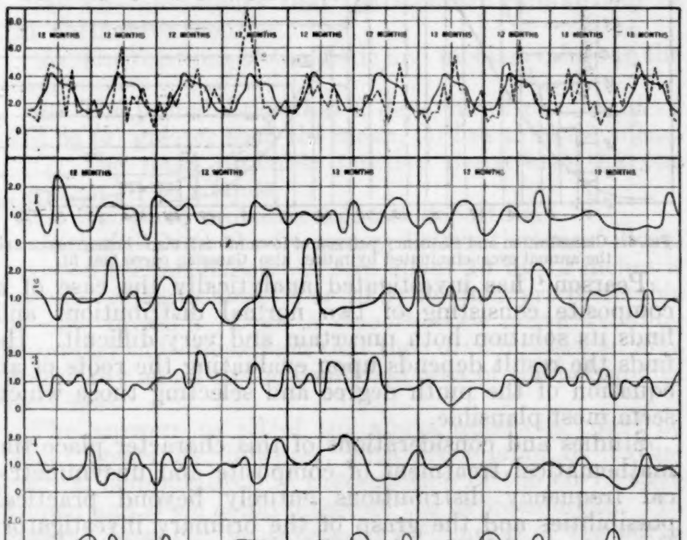

FIG. 4.—Monthly values of Iowa rainfall and ratios to monthly means. Top full line, annual cycle; dotted line, actual monthly values for 10 consecutive years. Remainder of diagram, consecutive values of monthly ratios. Traces 1, 3, and 5 derived from perfectly fortuitous drawings; 2 and 4, actual rainfall data. Real and fortuitous sequences practically indistinguishable.

tend to nurse into realism the creatures of the imagination.

(2) That the results due exclusively to the operations of chance must be fully evaluated for appropriate comparison with the supposed real results of any investigation in hand. In the attainment of these objects it is of paramount necessity that the original data be reduced to its most elemental form by the complete elimination of all known or obvious periodicities and other characteristic features assignable to some particular cause or associated with a particular time or season. Figure 4 illustrates the results before and after such adjustments have been made on certain rainfall data. As explained in the legend, the results of perfectly fortuitous drawings from the identical body of numbers are also shown in the figure. Without exception it is possible to secure results exactly similar to these, as to actual and fortuitous orders of succession, for any body of data whatever. Such a procedure brings the investigator face to face with the real problem of periodicity. Cyclical sequences derived from the real data that are indistinguishable in their principal features from like sequences deduced from the fortuitous drawings can not be claimed to have physical reality. Demonstrations of reality must be based on results drawn from the real data which can not in any way be duplicated from the fortuitous drawings. It is wonderfully instructive to any investigator to try out and compare for himself the results procurable from drawings, which deals exclusively with the one question of the order of succession of any body of data.

(3) *Frequency distribution—General remarks.*—For purposes of physical investigation of meteorological and like data, frequency distribution must be reduced to the most elemental form possible. The almost universal practice of classifying data on the basis of departure from a mean value is satisfactory only for data like temperature, pressure, etc., where there is no theoretical limit upon the magnitude of either plus or minus departures. Certain classes of data of which rainfall and wind velocity furnish good illustrations have definite zero classes. In such cases values less than zero are hypothetical and impossible. If this kind of data is classified on actual values from zero to the highest, then the resulting distribution for any long record will be highly composite and will most likely tend to be multimodal as shown in figure 5.

Departures from a mean value.—Whether departures from a monthly mean or a mean for the whole group of data are employed a classification by departures, of data having a zero class like rainfall, is unsatisfactory because in either case the zero values of data fall indiscriminately in different places in the frequency distribution.

Ratios to the mean.—A very satisfactory remedy for this difficulty is found by taking the ratio of the individual values of any variant to the mean either of a month, a year, or any other group, or the mean of the whole body of data may be the basis of the ratio. This method brings all zero values into coincidence at zero class and all mean values are coincident at unity or class 1.000. There is no limit to the values which may occur in excess of the mean. The method is essential in classifying data having an absolute zero class, but it is equally advantageous in cases of any other data. The computation of the ratios may seem to require much additional labor, but experience shows not only that subsequent work is simplified by the use of ratios but that such ratios make data, otherwise widely diverse, comparable on a reasonable basis of equality. Regions of light and

heavy winds, or of light and heavy precipitation, may be thus readily compared.

Moreover, taking the ratios to the monthly mean effectively eliminates features like the annual cycle. This result is also secured by taking departures from the same means. The latter method, however, introduces a heterogeneous mixture of plus and minus signs which are a fruitful source of errors of computation and are otherwise objectionable.

Figure 6 illustrates a classification of rainfall by ratios, attaining thereby what appears to be a closer approach to the elemental characteristics of the data than is perhaps otherwise possible. The curves and fortuitous drawings in figure 4 are derived from the same data.

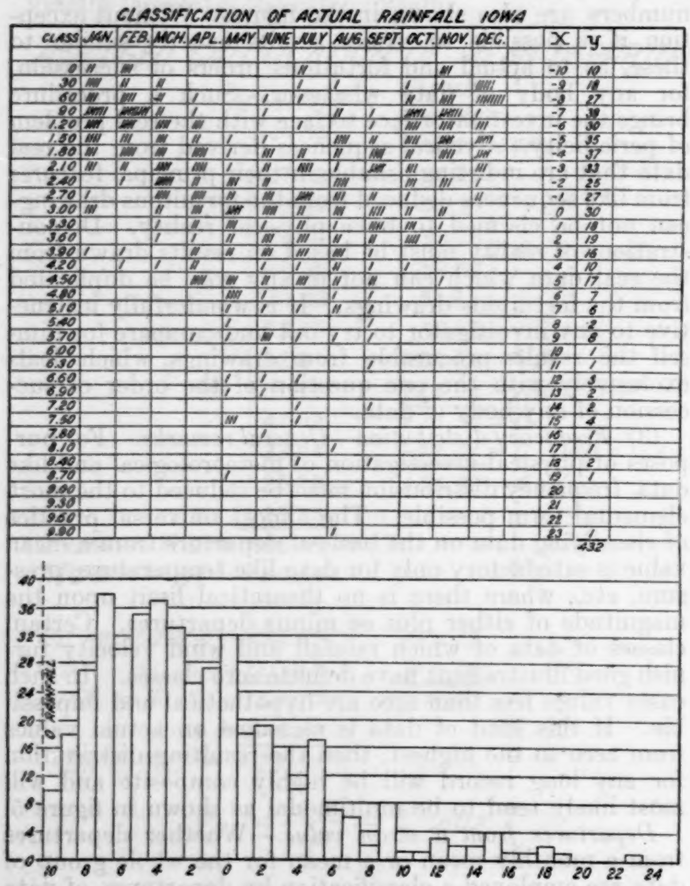

FIG. 5.—Classification and frequency polygon of Iowa rainfall; actual monthly means.

Normal and skew distributions, elemental and composite.—It is a question if any meteorological data exhibit a strictly symmetrical and normal distribution as defined by the Gaussian equations. Variations of temperature when brought into a homogeneous state of values of equal weight and free from diurnal and annual systematic changes appear to be very nearly symmetrical in distribution, but I do not think it has been demonstrated that even these values obey Gauss's law of distribution at all closely.

As a general proposition, all meteorological data form skew distributions well illustrated by diagrams like figures 5 and 6. The Gaussian equations of probabilities apply to these only in the crudest possible way. Even in many cases where the skewness of a distribution is slight, conformity to the Gaussian law is not satisfactory, probably because of some inherent complexity of the data. Take for example a very simple case in which the variations are due to only two separate causes, each of which is Gaussian in its action, we may write from a well-known principle in least squares—

$$\sigma = \pm\sqrt{a^2 + b^2}$$

in which a and b are the standard deviations of the separate causes of variation, respectively. Now if the two systems of variations have approximately the same mean value, then the composite distribution will be symmetrical but not elemental, and if a and b differ materially the distribution can not be fitted by a single Gaussian curve with any satisfaction. If, furthermore, the mean values for the two systems differ more or less the resulting distribution will tend to be unsymmetrical and may even have two definite modes.

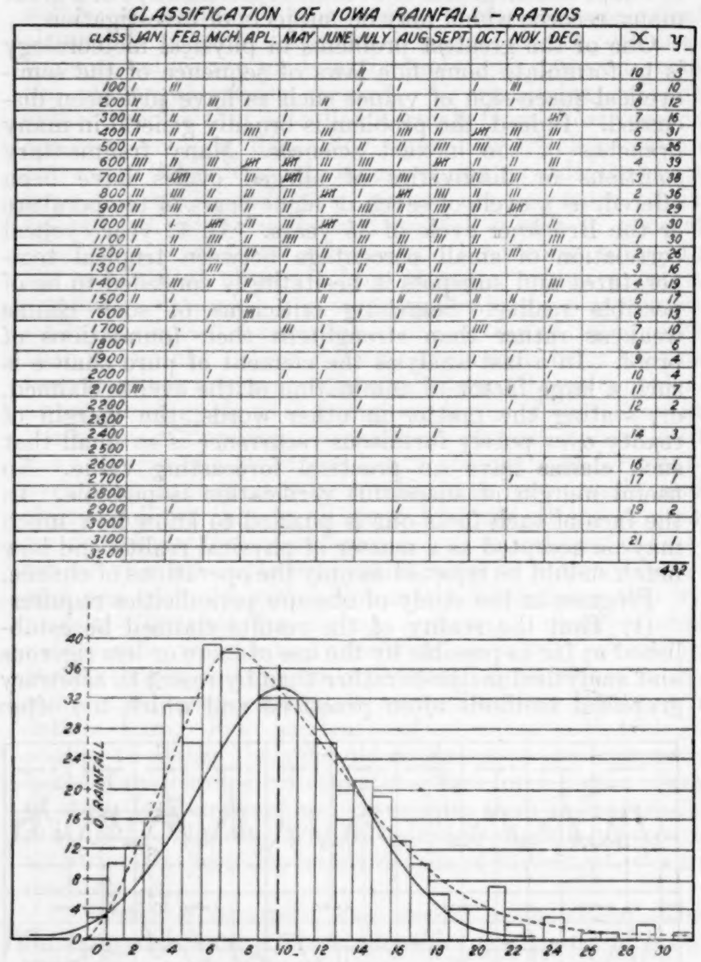

FIG. 6.—Classification and frequency polygon of Iowa rainfall made homogeneous and the annual cycle eliminated by ratios; also Gaussian curve best fit.

Pearson [4] has investigated analytically the case of a composite consisting of two normal distributions and finds its solution both uncertain and very difficult. He finds the result depends upon evaluating the roots of an equation of the ninth degree and selecting those which seem most plausible.

Studies and considerations of this character place the mathematical treatment of composite and unsymmetrical frequency distributions entirely beyond practical possibilities and the grasp of the ordinary investigator. Even the well-known formulæ and methods of Pearson for treatment of certain elemental types of skew distribution are prohibitive because of the great labor of computation entailed, especially when solutions are required for perhaps hundreds of cases. In addition, the result

[4] Pearson, Karl: Contributions to mathematical theory of evolution. *Phil. Trans. Roy. Soc.*, vol. 185, pt. 1, A, 1894, p. 71.

in the end may be disappointing because of the composite character of material handled and the imperfect fit of the theoretical curve to the actual data.

Notwithstanding all such serious obstacles the searching analysis of the frequency distribution of any body of data under discussion is a most essential as well as fruitful source of information, and the case is by no means so hopeless as it seems, because important and very useful phases of the whole problem can be solved most satisfactorily by empirical graphic methods which are ridiculously simple and certain compared with the laborious and possibly disappointing mathematical methods.

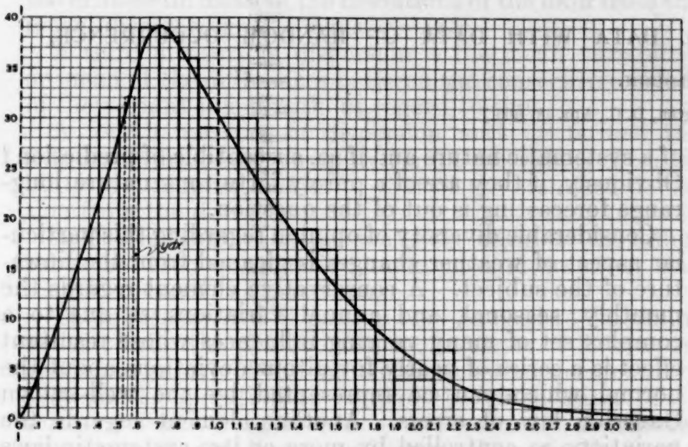

FIG. 7.—Distribution of Iowa rainfall ratios representing graphic integration of skew curve of best fit.

The skew distribution of Iowa rainfall ratios redrawn as figure 7 furnishes a good example, illustrating how the graphic method may be employed.

The more important quantities we wish to determine are:

(1) The modal or most frequent monthly amount of rainfall.

(2) The probability of the modal amount.

(3) The mid or median amount, than which a monthly amount is just as likely to be greater as to be less.

(4) The probability that the monthly rainfall will be the normal for month.

(5) The relations of the mode and median values to the mean.

(6) The probabilities that a departure from the mean will be (*a*) greater than the mean, (*b*) less than the mean.

(7) The most probable positive departure, the one having a 50-50 chance.

(8) The most probable negative departure.

Method.—Draw the frequency distribution carefully to scale on section paper. A size about 10 by 12 inches is ample. Squares about 8 or 10 to the inch are preferable as easy to read. Draw a smooth skew curve avoiding secondary inflections such that the curve incloses an area practically equal to the combined area of the polygon of rectangles.

The answers to all of the above questions could be found (generally, however, with great labor of mathematical computation) *if* the equation of the curve were known and *if* we could integrate the expression ydx. In general, however, no satisfactory equation of the curve can be found, and the integration of ydx is also difficult or impossible. It is perfectly easy, however, to perform a *mechanical integration* of the expression ydx for any free-hand curve, as in figure 7, by simply adding together the coordinates or y values at each intersection of the curve with successive vertical lines of the section ruling. One of the elements ydx is shown in dotted lines in the figure. In this case $dx = 0.05$. This operation of summation is very greatly facilitated by the use of a listing machine which preserves a record of the successive readings and permits introducing subtotals at certain desirable points, such as (*a*) at an ordinate which divides the area at the left of the mean into two equal halves. The place of this ordinate is estimated approximately by eye and the subtotal introduced as the listing proceeds; (*b*) at or near the modal value; (*c*) at or near the mean value of x; finally, (*d*) a subtotal should be taken at or near an ordinate which divides the area to the right of the mean in two equal parts. The grand total of the whole summation gives the total area of the distribution in units of squares of the coordinate rulings. If the readings of the ordinates are estimated to the tenth of a unit, the size and scale of diagram recommended will give a total area of about 1,000 squares, with the nearest tenth added, which is abundantly accurate.

Let A = total area of the distribution. (If this area is not quite equal to the total area (expressed in squares) of the polygons themselves, the curve may need to be adjusted in places to include better the desired area.)

Aided by the subtotals a, b, c, d, it is very easy to interpolate ordinates which accurately fix the following areas:

$$a' = \frac{\text{area from zero to mean}}{2}$$

The abscissa for the ordinate defining this area is the most probable negative departure (a 50-50 chance). Question (8).

The subtotal $b' = \frac{A}{2}$ defines the mid or median ordinate which divides the distribution into two equal parts. Question (3).

The subtotal c' defines the area from 0 to the mean or normal axis, viz, abscissa = 1.00

Subtotal d' locates

$$\frac{\text{area from mean to positive limit of ratios}}{2}$$

This defines the most probable value of rainfall ratio *greater* than the normal, the one having a 50-50 chance of occurring. Question (7).

From the data thus secured numerical answers are easily found for the Iowa rainfall data for 36 years represented by the distribution.

(1) The most frequent (the modal) rainfall we see by inspection is very approximately at $x = .700$; that is, 70 per cent of the monthly normal is the most probable value of monthly rainfall.

(2) The probability that the rainfall in any month will be the modal amount within a narrow limit, say between ratios 0.675 and 0.725 will be $858.6 \div 39$ = about once in 22 times—that is, although the modal rainfall is most frequent of any it will occur as a monthly amount within these limits only about once in 22 months.

(3) The mid or median value of rainfall ratio by interpolation from subtotal c' is 0.917—that is, it is an even chance that any monthly rainfall for this section of Iowa will be greater or less than 92 per cent of the monthly normal.

(4) The frequency for a mean monthly rainfall (ratio 1.00) from the curve is 30.3. The probability that the amount of a monthly rainfall will occur between a ratio say 0.995 and 1.025 will be $858.6 \div 30.3 = 28$—that is, the monthly mean rainfall within ± 0.025 will occur only once in about 28 months.

(5) We have seen the mode falls at $x=0.700$, the median at 0.917, and the mean or normal at 1.00.

(6) The probability that a monthly value of rainfall will be greater than the normal is measured by the ratio

$$\frac{\text{area greater than mean}}{\text{whole area}(=A)}=\frac{858.6-481.9}{858.6}=0.44$$

Hence the monthly rainfall will equal or be greater than the normal about 44 months in 100 and of course will equal or be less than the normal 56 months.

(7) For monthly amounts greater than the normal the percentage 1.36 is the probable amount.

(8) If a monthly rainfall is less than the normal it will be an even chance that the amount will be greater or less than 66 per cent of the normal, and it was shown under (1) that the most frequent of all monthly amounts was 70 per cent of the normal. Thus it appears that the most frequent monthly amounts and the probable amounts below the average are both about two-thirds the monthly normal.

Such are answers that are easily deduced by interpolations from the mechanical or approximate integration of such scale drawings of frequency distributions as shown in figure 7.

A STATISTICAL COMPARISON OF METEOROLOGICAL DATA WITH DATA OF RANDOM OCCURRENCE.

By H. W. CLOUGH.

[Weather Bureau, Washington, D. C., Apr. 18, 1921.]

SYNOPSIS.

Daily, monthly and annual means of meteorological data show fluctuations of varying orders of magnitude, which may be regarded as either of a fortuitous character or as presenting more or less systematic characteristics. Certain precise relations which are distinctive of purely fortuitous data are derived by both theoretical and empirical methods. These relations constitute criteria for determining the extent to which meteorological data differ from such fortuitous data.

Monthly and annual means of temperature are nearly Gaussian in their distribution, their deviations being of the nature of accidental errors, but the order of succession of their occurrence is not fortuitous. Rainfall data are more fortuitous in their characteristics than temperature. In a plot of unrelated numbers the two-interval is predominant, while in the case of most meteorological annual means the three-year interval is the most frequent. The variations of mean annual temperatures show systematic characteristics to a greater extent in the Southern Hemisphere and the low latitudes of the Northern Hemisphere than in the higher latitudes of the Northern Hemisphere.

Statistical criteria applied to the variations of the period of the solar spots disclose markedly systematic characteristics.

A period of recurrence of extremes of pressure at Toronto, averaging 32 to 34 days seems to be disclosed by a purely statistical method of treatment of the dates of highest and lowest pressure in each month for a long series of years.

Variability is a dominant characteristic of weather, particularly in temperate latitudes. In the Tropics the day-to-day fluctuations are negligible and the seasonal changes occur with clock-like regularity. The interdiurnal variability of temperature increases with latitude to about the Arctic Circle, then decreases somewhat. A plot of daily mean temperatures exhibits characteristic fluctuations with crests separated by intervals varying irregularly from 3 to 7 days or more. If these daily values be combined into weekly means and plotted there are again shown similar fluctuations but with longer intervals varying from 2 to 5 or 6 weeks. The same data combined into monthly means show, when the residuals are plotted, fluctuations apparently analogous to those of the daily data but with intervals between the successive crests varying from 2 to 6 months or more. Yearly mean temperatures at any locality when plotted show fluctuations which are indistinguishable from a plot of monthly residuals, the intervals being measured in years instead of months.

Thus daily, weekly, monthly, and annual means of meteorological data present fluctuations of varying orders of magnitude. The smaller day-to-day fluctuations are superposed upon the larger weekly fluctuations, the weekly upon the larger monthly, and so on until we arrive at the long secular variations measured by decades or even centuries.

The question arises as to the character of these apparently irregular fluctuations. Are they to be regarded as purely accidental and fortuitous or do they present characteristics which show them to be deviations partaking of a systematic nature and if so, susceptible of prediction? Obviously, if they are of a purely fortuitous nature long-range forecasting is out of the question.

Considerable diversity of opinion regarding this particular aspect of weather changes is gleaned from the literature of the subject. A conservative element regards the monthly, seasonal, and annual variations as due to a complex set of many varying influences whose resultant effect is a series of nearly fortuitous deviations about the normal which can be represented by the well-known Gaussian law of errors. Another element regards the variations as controlled by more or less systematic laws and as being essentially sequences of a quasi-periodic nature. Popular weather lore has for its basis an almost universal belief in the tendency of weather changes to be complementary, in other words for one extreme to be followed by the opposite within a short period.

Obviously it is possible by the employment of statistical criteria to determine the extent to which a given succession of meteorological data conforms to a purely fortuitous selection of similar data, and it will be the purpose of this paper to set forth the characteristics of data which represent purely accidental deviations about a mean and to illustrate by examples of meteorological data how and to what extent the latter differ from data of random occurrence.

CHARACTERISTIC FEATURES OF FORTUITOUS DATA.

There are two classes of data whose deviations present purely fortuitous characteristics: (1) A series of unrelated numbers, illustrated by a random selection of numbers between 0 and 100. In this class of data all values are equally probable. (2) A sample of the component data of a normal frequency distribution, illustrated by the sums of ten digits of random selection. The data of this class are also unrelated, but the various possible values of the variant are of unequal probability.

There are certain precise relations to which these two classes of data rigorously conform and which constitute criteria for testing the conformity of any series of observational data to these requirements. Any deviation from such a conformity indicates some systematic influence operating which results in a frequency curve of either a skew type or a symmetrical but composite type. In either case the curve of best fit by least square methods exhibits excesses in one part of the curve and deficiencies in another part.

Relations between indices of dispersion.—There are various measures of the dispersion or scatter, which, in the case of data showing a distribution of a

normal, elemental type, bear mathematically precise relations to each other, which are obviously valid only for a large sample of the component data. One measure of dispersion is the standard deviation σ, which is the square root of the mean of the squares of the deviations, $\sigma=\sqrt{\frac{\Sigma x^2}{n}}$. This value has certain properties which cause it to be extensively employed by statisticians as an index of the dispersoin of the data. The mean and the standard deviation completely determine the form of the Gaussian curve of the best fit to the data.

Another measure of dispersion is the mean deviation or the arithmetic mean of the deviations of the data from the mean, disregarding the signs, $v=\Sigma x/n$.

A third measure of dispersion is the mean variability or mean of the differences between the consecutive values of the variant taken without regard to sign.

A fourth measure of dispersion may be termed the standard variability, computed from the values of variability in a manner similar to that of the standard deviation from the deviations.

A fifth measure of dispersion is the mean of the differences between consecutive maxima and minima, and may be termed the mean range.

These measures of dispersion may be used to determine satisfactorily the characteristics of a series of data as regards the nature of the influences, whether accidental or systematic, operating to control the given data. In a series of data whose deviations are normally distributed these measures of dispersion bear mathematically precise relations to each other, as follows:

(1) *Relation of the mean deviation to the standard deviation, deduced by Cornu.*[1]—Cornu's theorem is "When the departures of a series of numbers satisfy the law of frequency of accidental errors, twice the quotient of the mean of the squares of the departures by the square of the mean departure (mean of the departures made without regard to sign) is equal to π, or in symbols, $\frac{2\sigma^2}{v^2}=3.14159+$.

The standard deviation is thus 1.253 times the mean deviation.

(2) *Relation of the mean deviation to the mean variability.*—Goutereau[2] showed that the mean variability of a series of unrelated numbers, as well as of a series of data whose deviations follow the law of errors, equals the mean deviation multiplied by $\sqrt{2}=1.414$.

Other relations distinctive of unrelated data.—There are certain other relations characteristic of a series of unrelated numbers which form useful criteria for discriminating between purely fortuitous data and data which are subject to some systematic influence and therefore not mutually independent.

(3) *Number of maxima in a series of unrelated numbers.*—Besson[3] showed that the number of crests appearing in a plot of unrelated numbers is one-third of the number of values.

(4) *Frequency of intervals between maxima.*—Of the intervals separating these crests, 40 per cent will be a two-interval, 33⅓ per cent, a three-interval, 17 per cent, a four-interval, 7 per cent a five-interval, and 2 per cent a six-interval. Thus the number of two-intervals is greater than the number of three-intervals in the ratio of 40 to 33.

[1] Cornu, *Annales de l'Observ. de Paris, Memoires.* Tome XIII, p. a220. Paris, 1876.
[2] Ch. Goutereau: Sur le variabilité de la temperature. *Annuaire de la Société météorologique de France*, 1906, 54: 122
[3] Besson, Louis. On the comparison of meteorological data with results of chance. (Translation by Edgar W. Woolard.) MO. WEATHER REV., Feb., 1920, 48:89.

The same paper[3] gives the probable number of single rises, double rises, etc., in a series of N numbers. Thus in a series of 100 numbers there are about 20 single rises, and the same number of single falls. It is desirable to know, in addition, the distribution of the single rises or falls as follows: (1) Isolated single rises; (2) single rise followed by a single fall; (3) single rise followed by a single fall followed by a single rise, etc. The total number of single rises and falls in N numbers is $\frac{5N}{12}$. I have deduced the following formula for the number of groups consisting of single rises and falls in a series of N numbers. If n represents the number of single rises or falls in such groups, the general formula is $\frac{5N}{12}\left(\frac{3}{8}\right)^2\left(\frac{5}{8}\right)^{n-1}$.

Thus in 1,000 numbers there are approximately 59 isolated single rises and falls, 37 groups with a rise followed by a fall or vice versa, 23 groups with three single rises or falls, 14 groups with four, 9 groups with five.

The writer has derived various other relations which are frequently useful in distinguishing between accidental and systematic deviations.

Select at random say several hundred numbers from a bowl containing perhaps fifty or a hundred of each of the numbers from 0 to 99, inclusive. The mean of these numbers will be 49.5. From the theory of probabilities it can be shown[4] that any two points selected at random on a line of given length are separated by an average interval of one-third the length of the line. Hence the mean variability of the above series of unrelated numbers is 33. The mean deviation is $33/\sqrt{2}=23.3$. In 100 such numbers there are approximately 33 maxima and 33 minima. It is found that the average of the differences between consecutive maxima and minima equals 49.5, or one-half of the possible extreme range. The mean variability is, as stated above, 33. *Hence the mean range is 1½ times the mean variability.* This relation is also valid for the component data of a normal frequency distribution, and is to be classed with the relations deduced by Cornu and Goutereau. The mean range of single rises or falls is approximately 45, or 91 per cent of the mean range of all rises or falls. According to Besson, five-eighths of the intervals between maxima and minima are single rises or falls. This indicates an important characteristic of a series of unrelated data, namely, a relatively large number of wide ranges from a very high to a very low value with no intervening value.

(5) *Distribution of data with reference to mean.*—Another relation characteristic of a series of random data, is the relative frequency of groups of the data above and below the mean. Obviously there are an equal number of values above and below the mean and an equal number of groups, containing 1, 2, 3, 4, or more values, above and below the mean.

If n be the number of values in each group above or below the mean, the probable frequency of such groups in N numbers is $\frac{(N-n-1)}{4(2)^{n-1}}$ or, if N is large, approximately $\frac{N}{4(2)^{n-1}}$. Thus in a series of N unrelated numbers between 0 and 99, there will be $N/4$ separate groups above 49.5 and $N/4$ groups below 49.5, a total of $N/2$ groups. Approximately 50 per cent of the total number of groups above and below the mean will be represented by a single value, 25 per cent by two consecutive values, 12.5 per

[4] *Encyclopedia Brittanica*, 11th ed., Vol. XXII, p. 385.

cent by three values, 6.2 per cent by four values, etc. As illustrating this criterion, the number of consecutive digits 0 to 9, either above or below the mean 4.5, in the fifth place of logarithms of successive integers from 100 to 700 were counted and there were found 4 groups with 14 consecutive digits above or below the mean, 1 group with 18, and 1 group with 19. The theoretical number of groups in a series of 600 unrelated numbers containing 14 consecutive numbers either above or below the mean is 0.02, showing that successive five-place digits in a table of logarithms, while apparently of random occurrence, are actually very far from being unrelated.

(6) *Smoothing formulæ.*—It is instructive to investigate the effect of smoothing formulæ on a series of numbers of random selection. A series of 900 unrelated numbers was smoothed by the formulæ (1) $\frac{a+2b+c}{4}$, (2) $\frac{a+2b+3c+2d+e}{9}$. The number of maxima and minima in the 900 numbers was 598. After smoothing by formula (1) the number was reduced to 384, or 43 per cent, of the 900 numbers, and after smoothing by formula (2) the number was 257, or 29 per cent. Thus the average interval between maxima after smoothing by formula (1) is approximately 4.7, and by formula (2) 7.

The following table gives the approximate frequency of various intervals:—maximum to the next maximum and minimum to minimum—expressed in percentages of the total number of intervals. Column 1 is the interval. Column 2 is the frequency for the unsmoothed data, according to Besson. Columns 3 and 4 give the approximate frequency after smoothing by formulas (1) and (2), respectively.

1	2	3	4
	Per cent.	*Per cent.*	*Per cent.*
2	40	3	2
3	33	30	4
4	17	24	9
5	7	18	15
6	2	13	18
7	0.5	8	16
8	....	4	11
9	....	1	8
10	....	....	6
11	....	....	4
12	....	....	3
13	....	....	2

Thus in the unsmoothed data the two-interval is the most frequent. After smoothing by formula (1) the three-interval is the most frequent, and after smoothing by formula (2) the six-interval is the most frequent.

SYSTEMATIC VS. ACCIDENTAL DEVIATIONS.

It has been stated that meteorological variations show analogies to both accidental and systematic errors of observation. An illustration afforded by target practice may serve to clarify the conception. The center of the target represents the mean and on a calm day the deviations of the shots to the left and right will be equal in number, and symmetrically distributed in conformity with the law of errors. On a windy day the deviations from the center will vary systematically with the direction and velocity of the wind. The shots thus have in addition to purely accidental deviations, a certain systematic deviation which they share in common, so that their deviations from the center are not wholly unrelated or independent of each other. Their deviations in this case will be unrelated only if taken from a new mean whose deviation from the center represents the systematic deviation common to all the shots on the windy day.

In the target practice on a calm day the ratio between the mean variation between the successive shots and their mean deviation will be $\sqrt{2}$. On a windy day, however, assuming the velocity to remain nearly constant from a direction transverse to the line of fire, the deviations from the center will show a systematic increase in magnitude on one side of the mean and a decrease on the other side, while their variability or scatter from each other will be practically unchanged. The ratio, therefore, of the mean variation to the mean deviation will be less than $\sqrt{2}$. If the deviations on all windy days were combined with those on calm days there would result a composite type of frequency curve compounded of two series of deviations each of which have the same variability but very different mean deviations referred to a common mean. This composite curve would be symmetrical but not elemental.

Meteorological data, as will be shown below, are similarly characterized by minor day to day fluctuations, which may be regarded as of the nature of accidental deviations, and larger fluctuations extending over a period of a week or more, analogous to systematic deviations. This tendency for weather to persist in definite types distinguishes any succession of mean daily, monthly, or yearly values of any meteorological element from a series of unrelated numbers.

CITATIONS FROM WRITERS REGARDING THE NATURE OF THE DEVIATIONS OF METEOROLOGICAL DATA.

It was stated above that diversity of opinion exists regarding the nature of the deviations shown by meteorological data. Prominent among those who have written on this subject is Angot,[5] who published in 1900 a discussion of the temperature of France for 50 years.

He computed the frequency of monthly departures exceeding $\frac{e}{2}$, e, $2e$, $3e$, and $4e$, where e represents the probable error of the departures. In all cases the actual frequency conformed practically to the theoretical frequency, and, to quote his exact words, "The physical causes that determine one month shall be warm or cold are so many and so complex that the net result is the same as that from purely fortuitous causes." In 1915[6] he made a further investigation of monthly and annual temperatures at Paris from 1851 to 1915 and concluded that "no relation can be made out between the temperature of a season and that of the following season; a warm summer will be succeeded indifferently by a warm winter, or by a cold winter. * * * In conclusion, the variability of monthly, seasonal, and annual temperatures in France follows exactly the same law as if the causes were purely fortuitous and it is not possible to forecast for months, seasons, or years by means of past phenomena."

On the other hand, Goutereau[7] pointed out that the normal ratio between the mean deviation and the mean variability was departed from in the case of certain meteorological data, particularly for a series of successive daily values, indicating the persistence of definite types of weather or systematic deviations from the normal. In such cases the departures may be of the nature of accidental errors but their order of succession is not fortuitous.

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[5] Angot, A.: Études sur le climat de la France; température, 1re Partie—Stations de comparaison. *Annales, Bur. cent. météorol. de France*, 1897, I. *Mémoires*, Paris, 1899, pp. B93–B170; *ibid.*, 1900, I. *Mémoires*, Paris, 1902, pp. B33–B118.

[6] Angot, Charles Alfred: Sur la variabilité des températures. *Comptes rendus, Acad. Agric. de France*, Paris, déc. 22, 1915, 1:789-792. Transl. by W. G. Reed. MO. WEATHER REV., July, 1916, 44.

[7] Ch. Goutereau: Sur la variabilité de la température. *Annuaire de la Société Météorologique de France*, 1906, 54: 122.

Newham[8] discussed the frequency of "spells" of wet and dry weather at Kew and found that by the law of chance 41 "runs" of 6 rain days should be expected at Kew in 10 years; actually there were 181 "runs" of 6 successive rain days.

Hann (Lehrbuch der Meteorologie, 1915, pp. 629–631) gives results by various investigators showing a tendency for the prevailing type of weather to persist and a decrease in the probability of a change with increasing duration of the type.

Brunt,[9] discussing the monthly residuals of temperature at Greenwich, 1841–1918, says, "It is probable that the greater part of the variations of the monthly means is to be regarded as being of the nature of random variations." He finds that the standard deviation of the monthly residuals corrected for the effect of all the periods found by the Fourier series is very little less than that of the uncorrected residuals and concludes that "the evidence from the standard deviation added to the rather fortuitous manner in which the periods actually formed seem to appear and die away, indicates that investigation of periods in monthly mean temperature is likely to afford very little help in weather forecasting."

The citations from Angot and Brunt fairly represent the views of many meteorologists regarding weather sequences. They either regard the various claims that have been made by investigators, that definite periods exist in weather phenomena, as due to fortuitous combinations that disappear with increasing length of record or quite fail to grasp the significance, from a purely statistical viewpoint, of sequences which can easily be shown to persist over long intervals of time.

STATISTICAL CRITERIA APPLIED TO METEOROLOGICAL DATA.

The problem of weather periodicity may be regarded as presenting two distinct phases. The first question that arises is the extent to which meteorological data exhibit variations analogous to the systematic deviations of physical measurements. Secondly, are these systematic variations periodic or at least quasi-periodic in their nature? In what follows, an attempt will be made to answer the first question by the application of the criteria which have been discussed earlier in this paper and in addition a partial answer to the second question will be developed along purely statistical lines of investigation.

The statistical criteria which have been employed may be enumerated as follows:

(1) Ratio of mean deviation to standard deviation.
(2) Ratio of mean deviation to mean variability.
(3) Relative number of maxima.
(4) Relative frequency of intervals between maxima.
(5) Relative number of groups above and below the mean and relative frequency of total values in each group.
(6) Relative number of maxima and interval-frequency after smoothing.

The numerical values of these various relations for a series of unrelated numbers have been stated above.

Angot confined his investigation to France and a few stations in contiguous countries. I have employed data from the United States, mainly from Schott's discussion of the Smithsonian temperature data.[10]

Angot stated that his conclusions were valid only for France, but it is probable that readers have not always borne in mind this limitation of his results.

TABLE 1.

Stations.	Years of record.	σ	v	u	$\frac{\sigma}{v}$	$\frac{u}{v}$	Maxima and minima.
		°F.	°F.	°F.			Per cent.
Paris	1851–1919	1.11	.91	1.30	1.22	1.42	62
Greenwich	1851–1900	1.15	.90	1.28	1.28	1.42	....
Montpelier	1851–1897	.97	.76	.94	1.19	1.24	....
Marseilles	1851–1897	.90	.77	.85	1.16	1.09	....
Toronto	1841–1908	1.30	1.04	1.29	1.27	1.24	62
Brunswick	1807–1870	....	1.42	1.13	....	.80	56
Salem	1786–1870	....	1.18	1.01	....	.86	62
New Haven	1780–1870	1.25	.99	.97	1.26	.97	56
Philadelphia	1790–1870	....	....	1.05	....	....	60
Baltimore	1817–1904	....	1.15	1.27	....	1.10	59
Cincinnati	1806–1870	1.30	1.01	1.30	1.29	1.28	63
St. Louis	1826–1870	....	1.26	1.55	....	1.23	64
Muscatine	1839–1870	....	1.28	1.64	....	1.28	62
Fort Snelling	1820–1870	1.01	1.59	1.97	1.20	1.24	61
Fort Gibson	1828–1857	....	1.28	1.74	....	1.36	80
Fort Leavenworth	1830–1870	1.78	1.46	2.14	1.24	1.40	68

Table 1 gives for various stations the length of record; the standard deviation, (σ); the mean deviation, (v); the mean variability (u); the ratio, $\frac{\sigma}{v}$, the ratio $\frac{u}{v}$; the number of maxima and minima expressed in percentages of the number of years in the record. The data employed are mean annual temperatures.

(1) The table shows that at most stations the ratio of the standard deviation to the mean deviation averages close to the theoretical ratio, 1.253. This essentially confirms Angot's conclusions and is undoubtedly of universal validity, in the case of monthly and annual means of temperature. He, to be sure, employed a different method for arriving at the same result. Both methods agree in showing that the deviations are distributed about the mean precisely as accidental errors of observation. This implies simply that the mean is the most frequent value and that small deviations are most frequent, and large deviations are relatively infrequent, in conformity with the law of the occurrence of errors.

Marked departures from this ratio signify either (1) a tendency to skewness, (2) a lack of homogeneity in the record, or (3) insufficient length of record. A tendency to skewness is shown by any inequality in the number of positive and negative deviations. As a rule, monthly and annual means of temperature are symmetrical in their distributions.

(2) This, however, by no means tells the whole story regarding the actual sequence of the deviations. When the second criterion, first employed by Goutereau, is applied there is at once apparent a very general departure from the theoretical ratio, $\sqrt{2}$ or 1.414. Paris and Greenwich records have almost exactly this ratio and the Fort Leavenworth record considerably exceeds it. All other stations show smaller ratios. New England stations yield especially low values, the mean deviation exceeding the mean variation. Stations in southern France have markedly lower ratios than at Paris.

A ratio less than the theoretical ratio implies that deviations above and below the mean tend to persist to a greater extent than if they were purely fortuitous. As in the illustration given above, in the case of target practice, a systematic tendency to a persistence of deviations above or below the mean is indicated by a small ratio.

If the data be smoothed by a formula involving at least five consecutive values and deviations be taken from

[8] Newham, E. V.: The persistence of wet and dry weather. *Quart. jour. Roy. meteorol. soc.*, London, July, 1916, 42: 153–162. Abstract in Mo. WEATHER REV., 44: 393.

[9] Brunt, D.: A periodogram analysis of the Greenwich temperature records. *Quart. Jour. Roy. Meteor. Soc.*, London, Oct., 1919, 45: 323.

[10] Atmospheric temperature in the United States. Smithsonian contrib. 277, Washngton, 1876.

these varying means, the ratio between the mean deviations and the mean variations will then closely approximate 1.414.

(3) The third criterion is the relative number of maxima and minima, which in a series of unrelated numbers, is approximately 66 per cent of the number of values.

According to the table, this percentage for annual means of temperature is generally less than 66, ranging usually between 56 and 64. The lowest percentage is in New England, while in the extreme west it exceeds 66 per cent. This excess indicates an excessive preponderance of successive alternations of warm and cold years and is probably confined to the extreme southwest since in Iowa and Minnesota there is the usual deficiency in the percentage.

Meteorological data, as a rule, have less than 66 per cent. For example, the yearly means of pressure at Madras, India, 1841–1919, yield 58 per cent; the yearly means of pressure at Stykkisholm, Iceland, 1846–1918, yield 58 per cent. The monthly residuals of pressure at El Paso, Tex., for 20 years yield 58 per cent.

Rainfall data are, however, more fortuitous in their characteristics than temperature. For example, the yearly temperature at Baltimore, 1817–1904, yields 59 per cent, while the yearly rainfall for the same period yields 69 per cent. The monthly residuals for the same period gave for temperature 60 per cent, for rainfall, 65 per cent.

(4) The fourth criterion classifies the intervals between maxima in percentages of the total number for each 2, 3, 4, 5, etc., interval. For a series of unrelated numbers the normal frequency of each interval is as follows: 2, 40 per cent; 3, 33 per cent; 4, 17 per cent; 5, 7 per cent; 6, 2 per cent; 7, 0.5 per cent.

TABLE 2.

Station.	Years of record.	Intervals. 2	3	4	5	6	7	8	Data.
		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	
Paris	69	40	29	17	7	5	2		Mean annual temperature.
Baltimore	87	30	33	20	14	4			Do.
New Haven	86	23	30	16	13	8	2		Do.
Toronto	68	32	32	30	6				Do.
Interior United States (Schott).	51	33	43	17	7				Do.
Dodge City, Kans.	15	30	46	15	8	2			Mean monthly temperature.
Madras	79	24	39	24	11	2			Mean annual pressure.
Stykkisholm	73	21	45	19	10	5			Do.
St. Louis	48	9	46	14	9	5	13	5	Do.
United States corn yield.	54	28	34	25	12				Mean annual yields.
Unrelated numbers.		40	33	17	7	2	0.5		

Table 2 gives for selected stations the relative frequencies. As a rule the 3-interval exceeds the 2-interval in meteorological data. At Paris the frequencies for the intervals 2 to 5, inclusive, are practically the theoretical frequencies for unrelated numbers. The 6 and 7 intervals however are two to four times the theoretical values. The preponderance of the 2-interval is an interesting feature, since it is unique in that respect among the stations in the table. At Toronto the number of 4-intervals is nearly equal to the number of 2-intervals. At New Haven the 2-interval frequency is only 58 per cent of the theoretical, while the 5-interval is double and the 6-interval 4 times the theoretical frequency.

The excessive preponderance of the 3 and 4 intervals is very suggestive of a tendency toward a 3 to 4 year period. This is especially marked in the pressure data at Madras and Stykkisholm, where the 4-interval is as frequent as the 2-interval, whereas the theoretical frequency is less than half.

This criterion has been applied to the yearly corn-yields of the United States and the result is given in the table, showing a strongly marked tendency to a three to four year period.

The question arises as to the probability that a longer record would materially change the frequencies given in the table. The values are based on less than 50 years record in many cases. It is found that samples of 50 unrelated numbers vary widely in this respect, some having a preponderance of 3-intervals and a disproportionately large number of 4-intervals. On the other hand where a systematic influence is operating, to cause a preponderance of a 3-interval as compared with the 2-interval, a 50 year record is probably comparable in precision to a sample of 100, or even 150 wholly unrelated numbers.

(5) The fifth criterion is one that brings out more clearly than the preceding ones any tendency toward a persistent deviation from the mean due to some systematic cause. Table 3 gives for various data the relative number of separate groups above and below the mean expressed in per cent of the total number of groups, and the relative frequencies of the number of values in the groups. At Paris the number of groups is 52 per cent of the number of years of record, showing an excess over the theoretical 50 per cent for unrelated data, while the percentage of single years in these groups is 61 per cent as compared with the theoretical 50 per cent. This confirms the previous deduction that the Paris yearly temperatures are very similar to data of random occurrence. The records at New Haven and Toronto, however, yield a much smaller percentage, 32 per cent. Baltimore yearly temperatures for 87 years yield 40 per cent. Schott's consolidated series for the interior United States yields 43 per cent and the Atlantic series yields 39 per cent, both showing a marked departure from a series of unrelated numbers. The monthly residuals of temperature at Toronto for 68 years gives 41 per cent while the monthly residuals of pressure gives 48 per cent, very

TABLE 3.

Station.	Years in record.	Number per group. 1	2	3	4	5	6	7	8	9	10	Number of groups.	Data.
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Paris	69	61	22	6	3	3	3	3				52	Mean annual temperature.
New Haven	86	41	22	4	7	11	4	4			4	32	Do.
Toronto	68	36	14	18	18		14					32	Do.
Baltimore	87											40	Do.
United States (interior)	51	41	23	14	13	5	4					43	Do.
United States (Atlantic States)	91	43	26	3	11	3	6	6	3			39	Do.
St. Louis	48	28	28	17	22	5						39	Mean annual pressure.
Toronto	68	45	24	14	5	5	2	1	2	1	1	41	Mean monthly temperature.
Do.	68	50	25	12	6	2	2	1	1			48	Mean monthly pressure.
Unrelated numbers		50	25	12.5	6.2	3.1	1.6	0.8	0.4	0.2	0.1	50	

nearly the 50 per cent for purely fortuitous data. Bigelow (*Am. Jour. Sci.*, August, 1910) published a table showing temperature departures for the whole United States for each month from 1873 to 1909, inclusive. These monthly departures yield 42 per cent, which is very near the result found for the Toronto monthly residuals. These results show clearly the tendency for prevailing types of warm or cold weather to persist.

The results, however, for pressure as shown by the Toronto 68-year record, shows that pressure variations are more fortuitous in their occurrence than temperature variations. In this respect variations in pressure are much like those of rainfall in showing little indication of systematic deviations in the monthly residuals.

Mielke[11] has compiled departures of yearly temperatures from 1870 to 1910 for 25 districts over the entire globe. The number of stations in each district varies from 4 to 100 or more. The percentage of groups above and below the mean was computed for each district and the results are shown in the following table in which the district percentages are arranged in order of increasing magnitude:

TABLE 4.

	Per cent.		Per cent.
California	30	China and Japan	50
Atlantic States	38	Western middle Europe	50
India	40	Austria	50
Tropical America	43	North Germany and Holland	50
Interior United States	43	Great Britain	51
South Africa	44	Northeast America (eastern Canada)	51
South America	45	South Russia	52
Mediterranean Sea	45	Ural	53
Northwest America	45	Eastern Siberia	53
Australia	46	Northwestern Russia	57
Southwest Siberia	48	Northern Europe	60
Southern United States	49		

There are 12 districts below 50 and 11 districts 50 or above. The districts with percentages below 50 are in the Southern Hemisphere, and the lower latitudes of the Northern Hemisphere, including most of the United States. The low value for the Atlantic States, 38 per cent, is almost identical with the value, 39 per cent, obtained from Schott's consolidated temperatures in the Atlantic States, comprising 91 years from 1780 to 1870. The districts above 50 include northern Europe and Russia. The excessively high values in northern Europe and northwest Russia illustrate the extreme variability of weather in high latitudes. According to Besson the number of single rises and falls in a series of 100 unrelated numbers is approximately 41 while in the district of northern Europe the percentage is 52, showing a tendency to a two-year period.

It is obvious that a marked deviation either above or below 50 per cent is indicative of systematic tendency in the variations. These results are interesting in showing how different are the characteristics of meteorological variations in different regions, and how unsafe it is to draw general conclusions from investigations covering a restricted area.

(6) The sixth and most significant criterion relates to the effect of mechanically smoothing the data by certain formulæ. The following table gives the relative frequency of the various intervals after smoothing by the formula $\frac{a+2b+c}{4}$ for the data (1) Schott's United States interior temperature; (2) Toronto mean annual temperature; (3) Paris mean annual temperature; (4) a series of unrelated numbers.

TABLE 5.

Interval.	(1)	(2)	(3)	(4)
2	....	5	4	3
3	7	18	23	30
4	13	18	27	24
5	27	18	23	18
6	33	9	8	13
7	13	0	8	8
8	7	22	4	4
9	....	5	4	1
10	....	5	....	....
	35	35	40.6	43

The numbers at the foot of the table are the relative number of maxima and minima in the smoothed data expressed as a percentage of the number of years in the record. This table shows clearly the systematic tendency to persistence of the same type of weather even at Paris where by Angot's and other criteria the data are nearly indistinguishable from data of random occurrence. Thus at Paris the 4-interval is the maximum and the 3 and 5-intervals are equal while the theoretical frequency gives the 3-interval as the maximum and the 5-interval is little more than half the 3-interval. The marked departure of the frequencies for Schott's temperatures, interior of United States, from the theoretical frequencies is a particularly striking feature, in view of the fact that the percentage of maxima and minima in the unsmoothed data is 67.

The interpretation of these results evidently is that the amplitude of the minor year-to-year fluctuations is relatively small compared with that of unrelated numbers, where, as shown above, the amplitude of the single rises or falls is but little less than the average amplitude of all rises and falls—45 as compared with 50. By smoothing, the small fluctuations of temperature disappear, leaving a relatively small number of the large fluctuations.

This criterion is of greater value than any of those previously mentioned for disclosing systematic tendencies in a series of observational data. The Schott temperatures yield by the application of the third criterion—that of Besson—a result which is identical with that of a series of unrelated numbers. The same is true of the Paris temperatures. By smoothing, the essentially systematic character of the data is clearly brought out.

STATISTICAL CRITERIA APPLIED TO SOLAR DATA.

The criteria above mentioned are applicable in all cases where it is desirable to determine whether systematic deviations are present in any given set of data. As an illustration of the value of such criteria the sunspot epochs of Wolfer have been examined and the results are given below. The variations of the 11-year period have long been recognized. Newcomb[12] discussed the variability of the period and concluded from a mathematical analysis of the data that the deviations in the length of the period from a normal period were of an accidental nature. Some extracts from his paper follow:

In discussing periodic phenomena in which the times of recurrence of a given phase are subject to irregularities, two hypotheses may be made. One is that underlying the periodic phenomena there is a primary cause going through a perfectly uniform period, but that on the action of this cause are superseded irregular actions which may delay or accelerate the occurrence of a phase without affecting the primary cause. When this is the case we shall have a series of perfectly equidistant normal epochs for the recurrence of the same phase, and the observed deviations from these epochs will be in the nature

[11] Mielke, Johannes: Die Temperaturschwankungen, 1870-1910. *Archiv. des Deutschen Seewarte*, XXXVI, 1913. Hamburg, 1913.

[12] Newcomb: The period of the solar spots. *Astrophysical Jour.*, Jan., 1901, 13:1.

of separate and independent accidental errors. If p be the true value of the normal period, then at the end of n periods, however great n may be, the time of occurrence of the phase will differ from np by a small quantity $\pm e$ indicating the irregularity in the general mean. This value of e will be the same no matter how great n may be.

The other hypothesis is that while there is still a certain normal mean period, this period is nevertheless subject to change in such a way that if a phase is once accelerated the advance thus produced will go on indefinitely into all subsequent phases.

By a least square solution he deduced the mean period to be 11.13 years and concluded that the deviations of the epochs from the mean epochs based on this length of the period were of an accidental nature and that the first hypothesis was the correct one.

In order, however, to justify the adoption of this hypothesis he found it nesessary to regard some of the observed phases as more or less erroneous, due to the imperfections in the record. He writes:

I think that these perturbations of the period about 1790 are to be regarded as errors rising from the imperfection of the record. * * * The fact appears to be that while modern observations show that the maximum follows the minimum by less than 5 years and between 6 and 7 years are required to again fall to the minimum, the older observations seem to place the two epochs nearly equidistant. I regard this only as resulting from the accidental errors of the observations, as we can scarcely suppose a change in the law of variation to have occurred. * * * The contrast between the sudden deviations in the residuals of the doubtful period and the small ones of the recent well-observed epochs, make it almost certain that the errors between 1770 and 1800 are due to imperfections of the record.

There are, as Newcomb pointed out, two classes of errors. One is that of the observations themselves; the other, the irregularities of the actual phase. He regarded both classes of errors as of an accidental nature.

It is obvious, therefore, that Newcomb found it necessary to cast doubt upon the accuracy of the epochs in order to establish his theory of accidental variations. The actual deviations were somewhat greater than the theory allows.

Clough (*Astrophysical Journal*, vol. 22, No. 1, p. 62), discussed this point and concluded from several converging lines of evidence, including the testimony of magnetic and auroral data, that the epochs of Wolfer were substantially reliable. Wolfer himself has found it necessary to reiterate that the accuracy of the epochs in the latter part of the 18th century was greater than some students seemed inclined to allow. He considers the variations in the length of the period to have apparently a periodic character.

The problem is thus one of considerable historic interest. Fortunately it lends itself readily to a purely statistical treatment and furnishes a peculiarly apt illustration of the value of the criteria which have been employed above on meteorological data.

The mean epochs for the maxima and minima have been formed by extending backward Newcomb's mean epochs. The average deviation of the observed from the mean epochs are for the maxima, 1.40 years and for the minima, 1.13 years, showing a much greater precision for the determination of the epochs of minimum. The mean variability of the deviations of the maximum phases is 1.56 years, and of the minimum phases, 1.27 years. The ratio between the mean deviation and the mean variability is 1.12 for both maximum and minimum deviations, showing a marked departure from the ratio 1.414, which would obtain if the deviations were of a fortuitous character.

Applying the fifth criterion there is found for each of the series of deviations of the maxima and minima that the number of separate + and − groups is 36 per cent of the number of values. This is markedly less than the theoretical 50 per cent for purely accidental deviations.

The sixth criterion, based on smoothed values, has been employed on the sunspot intervals and the results are a striking demonstration of the value of this criterion for distinguishing between accidental and systematic deviations.

In my paper, previously referred to, the successive intervals maximum to maximum and minimum to minimum were combined and smoothed by the formula $\frac{a+b+c}{3}$. The resulting values were plotted on Chart I of that paper, and showed fluctuations of a more or less regular character. In order to apply the criterion given above in connection with the formula $\frac{a+2b+c}{4}$ it will be merely necessary to smooth the successive 11 year intervals by the formula $\frac{a+b}{2}$. Regarding the values a and b or the interval from minimum to maximum and maximum to minimum, respectively, as the elementary data to be examined, it is obvious that the smoothing of the 11-year intervals, $a+b$, $b+a'$, $a'+b'$, etc., by the above formula gives smoothed values of a and b by the formula $\frac{a+2b+c}{2}$. It might seem that, since the value of b is systematically greater than of a in the ratio of 1.2 to 1.0, taking the average from 1610 to 1900, or according to Newcomb, 1.4 to 1.0, there would be an alternation of higher and lower values in the smoothed numbers. However, the actual deviations of the occurrence of the phases are of an order of magnitude that considerably exceeds the relatively smaller variations due to the systematic differences between a and b. There are in the smoothed values 19 maxima and minima, or 17, if a slight fluctuation showing an increase from 10.7 to 10.75 be disregarded, since the amplitude of this fluctuation is less than 1 per cent of the larger fluctuations. The total number of values is 54. $\frac{17}{54}$ is 32 per cent which is to be compared with 43 per cent, as stated above, if the data were purely fortuitous.

Classifying the intervals according to magnitude there are obtained the following frequencies expressed in percentages of the total number of intervals. Column (1) is the magnitude of the interval. Column (2) gives the theoretical frequency for fortuitous numbers.

(1)	(2)	(3)
2	3	..
3	30	..
4	24	27
5	18	13
6	13	20
7	8	20
8	4	13
9	1	0
10	..	7

Column (3) gives the relative frequency for the smoothed sunspot intervals. The mean interval length is 4.7 for purely fortuitous numbers. The average interval for the sunspot numbers is $\frac{54\times}{17} = 6.4$, or 35.2 years, since the unit interval is approximately 5.5 years.

The application, therefore, of these simple criteria shows conclusively that the deviations of the epochs of maxima and minima, instead of being accidental as Newcomb concluded, are systematic to a marked degree, to a greater extent indeed than in the case of any series of terrestrial meteorological data yet examined.

QUASI-PERIODIC NATURE OF THE SYSTEMATIC VARIATIONS DISCLOSED BY STATISTICAL METHODS.

In what precedes, systematic tendencies to a persistence of weather types have been shown to characterize mean values of meteorological elements, particularly temperature. The question arises as to the periodic or quasi-periodic nature of these systematic variations. It is possible by purely statistical methods to show that there is a marked preponderance of certain intervals of recurrence of like phases in these variations. For example it has been shown that the three-interval is the most frequent interval in most series of meteorological data and some records, for example the mean annual pressures at Madras and Stykkisholm show such a preponderance of the three-interval that a three-year period may be said to be the most prominent one in annual means. I have not employed to any extent in this discussion data outside of the United States, but it is well known that in the Tropics and in middle latitudes of the Southern Hemisphere, the three-year period is clearly obvious from mere inspection of the plotted unsmoothed data, and it is scarcely necessary to apply any of the criteria which have been employed on data in high latitudes. With increasing distance from the Tropics, especially in the Northern Hemisphere, the fluctuations become more irregular and finally become nearly indistinguishable from those of unrelated data. The necessity for smoothing the data then arises in order to bring out any tendency to systematic variation. The fact that in certain regions, which correspond closely to the belt of maximum storm frequency, the variations are of a nearly fortuitous character, and there is a marked seasonal inequality in their systematic characteristics, corresponding to the seasonal shifting in latitude of the storm belt, points to the obvious conclusion that investigations of these systematic variations, which renders possible long-range forecasting, should first be restricted to regions in low latitudes and in longitudes relatively free from cyclonic action. Thus in the United States, the Southern States and the region west of the Rocky Mountains should exhibit more regularity in the long period fluctuations than other regions.

It should furthermore be borne in mind that monthly residuals of rainfall are more nearly fortuitous in their occurrence than temperature data, so that it would be rash to draw conclusions from an examination of rainfall data alone. The haphazard character of rainfall, particularly in summer, is well known.

It is obvious that the segregation of long period fluctuations from those of shorter duration, which is facilitated by a smoothing process, is the preliminary step in the investigation of meteorological data. In many cases simple inspection of the smoothed data, bearing in mind the criteria based on smoothing formulæ, discloses a more or less regular periodicity. Thus the curves illustrating the 7-year cycle (Cf. Maurer, *Archives des Sci. Phys. Nat.* Geneva, May, 1918; and Clough, Mo. WEATHER REV., Oct., 1920, **48:** 593–597) speak for themselves when it is remembered that in the case of fortuitous data, similarly smoothed, the most frequent interval is the three-interval, and the average interval is 4.7. It is difficult to understand how any other possible treatment of the data can strengthen the conclusions which necessarily follow from simple inspection of smoothed data in which periodic recurrences are so clearly evident as in the case of the 3-year and 7-year intervals.

The 35-year Brückner cycle is another instance of the determination of a periodic recurrence by inspection of curves of smoothed data. Brückner employed a slight modification of the ordinary smoothing process which leads to similar results. For exhibiting a 35-year cycle, 5-year means sufficiently smooth out the minor fluctuations to disclose the larger periodicity.

The monthly periodicity.—The existence of a weather periodicity apparently coinciding with the synodic rotation of the sun or the synodic revolution of the moon has been affirmed by many and there is an extensive literature dealing with the subject. One may be tempted to think it incredible, in view of the magnitude of research which has been expended on this problem, that there should be no real foundation for such assumptions. It is not necessary, however, to assume that either the solar or lunar periods are directly related to the supposed period, whose length may be sufficiently near either of these periods to lead to the plausible assumption that a real solar or lunar influence was in operation.

Passing over consideration of the vast literature of the subject, extracts will be given from a paper by Koeppen [13] summarizing an exhaustive investigation which he made in examination of the claims of lunar periods in the weather. After pointing out the fallacies commonly met with in such claims, he writes:

> Nevertheless, the application of correct methods has brought out several points wherein there are signs of a lunar influence, and these must be further investigated. On the one hand these signs indicate an atmospheric tidal movement, very slight, to be sure, and of infinitesimal effect upon weather and wind, as are the daily barometric variations in any case. On the other hand they point to more or less considerable fluctuations of about one month's duration; the regularity of these swings leaves it an open question whether they belong with one of the periods of the lunar revolution or of the sun's rotation, for these have similar durations.

He investigated pressure variations in Europe between 1755 and 1912 and concludes that while there is some systematic tendency for a recurrence of similar conditions about a month apart, there is no evidence of any regularity or persistence of a definite relation to the lunar synodic period throughout the entire series.

The concurrence of much evidence indicating a period of about one month led the author to develop a statistical method by which it seems possible to prove or disprove the existence of a period of such length. This is based on the fact that if there is selected alternately at random a number between 1 and 30 and a number between 31 and 60, the mean *difference* between these two numbers will be 30 and will be distributed symmetrically about this mean. If, therefore, we have a record of the dates of highest and lowest pressure for each month for, say, 50 years, at any locality and take the intervals between the dates of highest or of lowest pressure for two consecutive months, a month being approximately 30 days in length, these *intervals*, if the dates are of purely fortuitous occurrence, will have a maximum frequency of 30 days and the intervals above and below 30 days will decrease in frequency to a minimum for intervals of 0 and 60 days.

There were available the dates of highest and lowest pressure at Toronto for each month from 1840 to 1915. The intervals were tabulated separately for the years 1840–1879 and 1880–1915, also for the months April to September and October to March.

[13] *Meteorologische Zeitschrift*, 32: 180–185, April, 1915. (Translated by C. Abbe, Jr., in Mo. WEATHER REV., April, 1915.)

The following table gives for the warmer half of the year the relative frequencies of the intervals for each 10 days between 10 and 50 days:

Table 6.

	10-19	20-29	31-40	41-50
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1840-1879	16	26	34	23
1880-1915	17	26	34	23

The two halves of the period of 75 years show practically identical distribution. It is clearly obvious that a markedly unsymmetrical distribution has persisted throughout the entire period in summer, 43 per cent of the total number of intervals between 10 and 50 being below 30 and 57 per cent above 30. The mode for the entire period is approximately 34.

The following table gives the relative frequencies for the winter months:

Table 7.

	10-19	20-29	31-40	41-50
1840-1879	19	29	32	20
1880-1915	16	34	33	16

Thus for the entire period the distribution is practically symmetrical, with the mode slightly above 30.

The following table gives the interval frequency for the dates of maxima and minima separately for the two halves of the year:

Table 8.

MAXIMA.

	10-19	20-29	31-40	41-50	10-29	31-50
Winter	19	28	33	20	47	53
Summer	17	27	32	24	44	56

MINIMA.

	10-19	20-29	31-40	41-50	10-29	31-50
Winter	16	35	32	17	51	49
Summer	16	24	37	22	40	59

Examination of these figures shows that in the warmer half of the year the distribution of the intervals for both maxima and minima is of marked asymmetry. In winter, however, the intervals based on the dates of minima are of practically symmetrical distribution, while the maxima yield a distribution with a slight tendency to asymmetry, not, however, so pronounced as in summer.

The difference between the results for winter and summer may be plausibly accounted for by the well-known tendency for HIGHS and LOWS to be of more intense development and rapid movement in winter. The extreme pressures are confined to a much smaller area when the systems are intensely developed and consequently a more nearly fortuitous occurrence of the dates of extreme pressures at any one locality would result. Low pressure areas, being more variable in their departures from the normal than high areas and with the extreme reading more localized, there would naturally result a greater tendency to fortuity in the dates of occurrence of lowest pressure.

Suppose, for example, in addition to the Toronto data we had similar data for Rochester. We should expect to find, as in fact we actually do, more agreement between the dates at the two places in summer than in winter and in winter there would be closer agreement between the dates of maxima than of minima.

Thus if there is a tendency for systematic recurrence at intervals somewhat greater than 30 days, as seems to be indicated by the results for the warmer season, this tendency would be modified or even entirely obliterated by the greater tendency to fortuitous occurrence in winter, particularly for extremes of low pressure.

A further compilation was made of the intervals between the dates of maximum pressure in each month and that of the second month following. The most frequent interval, if the dates were of purely fortuitous occurrence would be 60. Actually the most frequent interval was around 65, which is a double 32 to 33-day interval.

It should be understood that the results by this method are not to be interpreted as indicating the probable length of the monthly periodicity with any degree of accuracy. All that may be reasonably deduced from the facts here presented is that there is a systematic tendency for the recurrence of periods of high pressure, particularly in summer, at intervals somewhat greater than 30 days. The tendency for a purely fortuitous occurrence of the dates in winter, particularly so for the dates of minima, is what we should, *a priori*, expect. This being the case, a marked departure from a symmetrical distribution, which occurs in summer and has persisted for 75 years as shown by the close agreement of the results for the two halves of the period, can not be explained other than as a result of a systematic tendency for the dates of extremes of pressure to depart from a purely fortuitous occurrence. The question as to the actual average length of the period and to what extent it may vary in length from time to time is left unanswered. Other evidence, however, indicates that this periodicity may have a variable length over a range of a week or more and hence investigators who have observed recurrences which they regarded as of solar or lunar origin, may have been misled by the apparent coincidence of a minimum length of the monthly periodicity with solar or lunar periods. When the period resumed its normal length the apparent coincidence disappeared. Thus Koeppen's results which require for their explanation the hypothesis of a systematic tendency to a monthly periodicity are plausibly explained by variations in the length of the period.

THE MEAN VARIABILITY AS A STATISTICAL COEFFICIENT.

The difficulty of applying the ordinary Theory of Errors to meteorological computations, on account of the peculiar nature of the meteorological variables as contrasted with that of the mathematical variables,[1] has often been recognized.[2] If the arithmetic mean of a series of values is to be the value most worthy of confidence, and is to have any significance and correspond to something physical, then the individual values from which it is computed must be distributed about it according to the Law of Gauss—the deviations from the mean must obey the laws of fortuitous errors.[3]

There are two equivalent tests which are ordinarily applied in order to determine whether or not the individual deviations from the mean are due to fortuitous

[1] L. Besson: On the comparison of meteorological data with results of chance. Mo. WEATHER REV., Feb., 1920, 48: 89.

[2] V. H. Ryd: On computation of meteorological observations, *Danske Meteorologiske Institut*, 1917.

[3] Angot: *Annales du Bur. Cent. Mét.*, 1895 and 1900; and *Annuaire de la Soc. Mét.*, 51, 1903.

causes: (*a*) If there are N numbers, there should be found $f(x)N$ of which the absolute deviation is equal to or greater than x; theory gives the value of $f(x)$; (*b*) the value of the expression $\frac{2N\Sigma\delta^2}{(\Sigma\delta)^2}$ should be 3.14159 . . . Now meteorological data may satisfy both these tests without at all fulfilling other conditions equally demanded by theory; we have here a good illustration of the oft-repeated warning against drawing conclusions from summary coefficients alone, such as the mean. In the present instance, the *order* in which the numbers appear is of great significance, and the following relation must also hold:[4]

If the deviations from the mean are to be likened to fortuitous errors, then the ratio of the mean variability to the mean deviation must be equal[5] *to* $\sqrt{2}=1.414$ . . . The variabilities and deviations are taken without regard to sign.

Drawings from a sack containing balls, on each of which was marked an observed daily temperature, would give a succession vastly different from the succession actually observed: Long series of increasing or decreasing values would be less frequent in the drawing than in the observing, and the mean variability would be greater in the former; in fact the ratio of mean variability to mean deviation in the case of series of daily temperatures turns out to be but little more than half the theoretical value; chance would give the deviations which are observed, but would not give the succession which is observed. *Yet both the actual and the chance successions satisfy the two tests mentioned above.*

It has been pointed out by Besson (*op. cit.*) that if a variable is taking on random values, it does not follow that the succession of the signs of the variations will obey the laws of chance; Goutereau points out further that the deviations from the mean may not be fortuitous even if they follow the Law of Gauss.—*Edgar W. Woolard.*

[4] Ch. Goutereau: Sur la variabilité de la température, *Annuaire de la Soc. Mét. de France*, 54, 122-127, 1906.

[5] The demonstration, by Maillet, is given by Goutereau, *op. cit.* The absolute difference between a number and the next consecutive number is the variability.

THE VARIATE-DIFFERENCE CORRELATION METHOD.

For correlating daily changes of barometric height at Halifax and Wilmington, Miss Cave[1] made use of a formula, devised by Pearson, giving the correlation coefficient between the differences of successive daily readings at the two stations; and remarked that this formula would apply to any case in which it was desired to correlate the difference of one pair of quantities with the difference of another pair; no comments on where this procedure might be desirable were offered, however. Later, Hooker[2] independently pointed out that the correlation coefficient between two variables, for each of which a series of observations is available, is a test of similarity of the two phenomena as influenced by the totality of the causes affecting each of them; when, therefore, the observations extend over a considerable period of time, certain difficulties arise which find no precise parallel in the case where the whole of the observations refer to the same moment of time: If a diagram be drawn, showing by curves the changes of the two variables during the period under consideration, some relation will often be suggested between the usually smaller and more rapid alterations while at the same time the slower "secular" changes may or may not exhibit any similarity. If, then, the correlation coefficient be formed in the ordinary way, employing deviations from the mean, a high value will be obtained if the "secular" changes are similar (this value being almost independent of the similarity or dissimilarity of the more rapid changes), but a value approximating to zero if the "secular" changes are of quite dissimilar character even though the similarity of the smaller rapid changes be extremely marked; deductions drawn from ordinary correlation coefficients may be very erroneous. In order to get rid of the spurious correlation arising from the fact that both variables are functions of the time, the correlation coefficient may be formed between the *variations*, or first differences, of the quantities, instead of between the quantities themselves. After this method had been in rather extensive use for some time, Pearson pointed out that it was valid only when the connection between the variables and the time was linear.

[1] F. E. Cave-Browne-Cave: On the influence of the time factor on the correlation between the barometric heights at stations more than 1,000 miles apart, *Proc. Roy. Soc.*, 74:403-413, 1904-1905.

[2] R. H. Hooker: On the correlations of successive observations, *Jour. Roy. Statistical Society*, 68:696-703, 1905.

The name Variate-Difference Correlation was given by Pearson[3] to a generalization of the preceding artifice, in which it was demonstrated[4] that if the variables are randomly distributed in time and space, the correlation between the variables and that between the corresponding *nth* differences will be the same; and that when this is not the case, we can eliminate variability which is due to position in time or space, and so determine whether there really is any correlation between the variables themselves, by correlating the 1st, 2d, 3d, * * *, *nth* differences: *when the correlations between the differences remain steady for several successive orders of differences we may reasonably suppose we have reached the true correlation between the variables.*

The complete theory of the method was worked out by Anderson[5] and subjected to critical examination by Pearson (*op. cit.*), who found that, as usual, the theoretical formulæ were only roughly approximated to in practice unless a great number of observations were at hand.

There has been no source more fruitful of fallacious statistical argument than the common influence of the time factor. The difference method of correlation is one of great promise and usefulness. The very frequent and superficial statements that such and such variables, both changing rapidly with the time, are essentially causative cease to have any foundation when the difference method is applied.[6]—*Edgar W. Woolard.*

[3] Beatrice M. Cave and Karl Pearson: Numerical illustrations of the variate difference correlation method, *Biometrika*, 10, 340-355, 1914-15.

[4] "Student": The elimination of spurious correlation due to position in time or space, *Biometrika*, 10, 179-180, 1914-15.

[5] Nochmals über "The elimination of spurious correlation due to position in time or space," O. Anderson, *Biometrika*, 10, 269-279, 1914-15.

[6] Illustrations of the method are given by Cave and Pearson, *op. cit.*, and by G. U. Yule, *Introduction to the Theory of Statistics*, 5 ed., 1919, pp. 197-201; see also T. Okada, Some researches in the far eastern seasonal correlations, MO. WEATHER REV., 1917, 45: 238, 299, 535.

NOTE ON PROF. MARVIN'S DISCUSSION OF "A POSSIBLE RAINFALL PERIOD EQUAL TO ONE-NINTH THE SUN-SPOT PERIOD."

By DINSMORE ALTER.

[University of Kansas, Lawrence, Kans., Apr. 26, 1921.]

I have naturally been much interested in Prof. Marvin's conclusions[1] regarding my paper.[2] I am very sorry that it is impossible for us to agree concerning the possibility of the phenomenon discussed, and especially concerning the legitimacy of the method employed. A further statement concerning some of the points raised by him may be in order.

[1] MO. WEATHER REV., February, 1921, 49: 83-85.

[2] *Ibid.*, pp. 74-83.

In no place in the paper is there any reference to a systematic variation in the length of the sun-spot period as claimed in the opening paragraph and also later in Prof. Marvin's discussion. The figure which gives the length of the period for each year is not in any way based on such a supposition and applies equally, whether, as believed by Newcomb, the differences are accidental variations or, as by Lockyer and Clough, they are systematic. The basis of this curve is the observed epochs of maxima and minima, and its accuracy depends solely upon the accuracy with which these have been observed. I refer the reader especially to page 76 of my paper in the February number of the MONTHLY WEATHER REVIEW, where I have discussed the possible inaccuraries.

Prof. Marvin, speaking of the method of tabulation of rainfall data, says: "Exactly the same method has been used by meteorologists almost for centuries." He then proceeds later to criticize the points in which this method differs from the old. To do this he gives a table of months skipped or repeated and shows how much rainfall fell in Washington, D. C., during these months. I would make three replies to this criticism.

(A) The exact form of the method is comparatively new but is already standard. Prof. Schuster, on page 75, *Philosophical Transactions of the Royal Society*, 1906, Volume 206A, makes the first use of it that has come to my notice. In this place he says: "Thus for a period of $7\frac{3}{4}$ years the alternate rows were formed of 15 and 16 figures. This gives 31 intervals of six months for two complete periods, or, on the average, $7\frac{3}{4}$ years. In the last column alternate numbers were missing, and this column was omitted in the calculations of A and B, the number being chosen to correspond to the number of columns retained." As an example of a problem in which numbers were repeated I wish to quote from page 461 of Prof. Turner's paper "On the Fifteen Month Periodicity in Earthquake Phenomena" published in *Monthly Notices* for April, 1919. "The cycle was identified (in the B. A. Report for 1912) as of 104/7 months, which can be approximately dealt with either—

(*a*) by repeating a month at the end of seven complete sets of 15 months ($7\times15=105$), or

(*b*) by collecting sets of 15 months in sevens without repetition and then shifting the initial month one to the right for each set.

The first method (*a*) was adopted in the 1912 report. As a variant the second method was adopted here."

(B) In my paper, totals of rainfall are not the data upon which the arguments were based (although their use would have been legitimate), but ratios between two tables built, each with the same months repeated or averaged, the one using actual the other normal rainfall values. This is clearly stated on page 77 of my paper. The most serious objection that could possibly be raised is that the skipping of months lessens the weight of the argument in direct proportion as the number skipped is to the total number. Thus, if one month in six must be skipped in a certain six years' stretch of data and none in another five years' stretch, the number of months used is the same in each case and the weights of the two stretches are equal. Even this slight objection can not apply if the months are averaged instead of skipped.

(C) The method is legitimate in all cases, no matter how frequently months must be repeated or averaged, but even though one should assume the legitimacy of Prof. Marvin's criticism there would be almost no application to the conclusions of the present paper, since almost his whole argument is based on the large amount of repetition necessary in years earlier than the earliest for which we have state averages.

Prof. Marvin criticizes my application of the method of least squares, as he claims, to rainfall. Regardless of the merits of his objection to its application to rainfall data, I would call attention to the fact that I have not so applied it, but have considered only the differences and similarities of two curves already obtained without its use. The whole argument of the paper is based on the similarity of these curves obtained from different stretches of years.

Long records are certainly needed. It is for lack of long State averages that I included the word possible in the title. I would call attention, however, to the fact that the data used for the average State run through approximately 18 complete cycles—not a short record, as tabulations of physical data usually run.

ERRATA: On pp. 78–79, February REVIEW, legends for Figs. 3, 4, and 5 apply to figures marked 4, 5, and 3, respectively.

DATES OF THE OPENING OF ONEIDA LAKE, N. Y., 1869–1921.

By ERNEST S. CLOWES.

[1309 East Adams Street, Syracuse, N. Y., Apr. 30, 1921.]

Oneida Lake is the largest in area in central New York, famous for the beauty and number of its lakes. It is about 25 miles long and averages about 6 miles wide over the greater portion of its length. It is distant 25 miles from Lake Ontario, and its central point is approximately the same distance northeast of the city of Syracuse. Its northernmost point is in latitude 43° 15′.

Although the largest, it is the shallowest of the larger lakes of this region, its average depth being 45 feet and its deepest but little more than 60 feet, as contrasted with the 600-foot depth of Cayuga and Seneca Lakes. For that reason it freezes early in the winter and stays frozen usually until spring is fairly set in, although in this variable climate snowstorms after its opening are not unknown. The country immediately surrounding it is flat and marshy on the south and rolling on the north. No river of any size flows into it, but its outlet at its western end is the Oneida River, a navigable stream used as part of the route of the New York State Barge Canal.

The record of its opening in the spring given here was kept by residents of the village of Constantia, on its northern shore. The ice in the spring breaks up suddenly at the last and in the space of a few hours is blown ashore or carried out down the river, so that the opening of the lake may usually be put down as occurring on a single day. The record follows:

1869	April 21	1896	April 19
1870	April 13	1897	April 2
1871	March 15	1898	March 17
1872	April 22	1899	April 20
1873	April 26	1900	April 18
1874	April 15	1901	April 14
1875	April 17	1902	March 29
1876	April 21	1903	March 21
1877	April 19	1904	April 17
1878	March 15	1905	April 11
1879	April 24	1906	April 6
1880	March 5	1907	April 1
1881	April 23	1908	April 2
1882	March 19–20	1909	April 8
1883	April 20	1910	March 25
1884	April 5	1911	April 15
1885	April 25–26	1912	April 18
1886	April 2	1913	March 22
1887	April 24	1914	April 16
1888	April 18	1915	April 12
1889	April 12	1916	April 14
1890	March 27	1917	April 3
1891	April 13	1918	April 15
1892	April 6	1919	March 21
1893	April 14	1920	April 4
1894	March 21	1921	March 16
1895	April 19		

The average date for the whole period is April 8, but the chief interest lies in the averages for 10-year periods. For convenience these were taken for the 50 years from 1872 to 1921, inclusive, and show for the decades in Table 2. For comparison Table 2 also shows the temperature means of the three months, January, February, and March, at Oswego, N. Y., which were averaged for each year and then 10-year averages worked out. These resulted as follows:

TABLE 2.—*Mean dates of opening and temperatures at Oswego, N. Y.*

Period.	Mean date.	Temperature at Oswego, N. Y.
1872–1881	Apr. 13	27.4
1882–1891	Apr. 10	24.8
1892–1901	Apr. 9	25.0
1902–1911	Apr. 4	26.0
1912–1921	Apr. 5	25.5

The Oswego station is about 30 miles from the lake. With the exception of the first decade the results conform to the theory that the lake is an indicator of the intensity of the winter cold and the earliness of spring combined. One factor which may in part be responsible for discrepancies is that of relative cloudiness and sunshine. Central New York has an excessive amount of cloudiness in winter but the amount, especially in March, is very variable, and it is possible that in some cases where the temperatures were mild the excessive cloudiness prevented the melting of the ice as rapidly as would have occured with normal sunshine. The reverse might also have been the case in some instances, but generally speaking, the melting of the ice seems to be a function of the temperature during the winter and early spring and thus to indicate, in a way, the weather character.

This would seem to indicate that although the lake opened this spring earlier than in any year since 1880, and more than three weeks earlier than the average date, there is a tendency shown in the last 10 years toward a return toward average conditions.

Incidentally, it may be noted that in the record-breaking mild winter of 1889–90 the ice in the lake broke up several times, the last date being March 27. The two years when the lake made its record for late opening, 1873 and 1885, both had hard winters previously, but in 1918 and 1920, when the winters were equally severe, the lake opened little if any later than the average, due to unusual warm periods late in March. The real effect can only be seen by averaging a period at least a decade in length.

The lake records are now kept by Fred Beebe, of Constantia, to whom, and to Miss J. M. Smith, of that village, who has the early records in her possession, the author's thanks are due, as they are also to Mr. Julius G. Linsley, official in charge of the Oswego station of the Weather Bureau, who afforded him ready access to the climatological records of the office.

REGISTRATION OF THE INTENSITY OF SUN AND DIFFUSED SKY RADIATION.[1]

By A. ÅNGSTRÖM and C. DORNO.

[Stockholm, Sweden, and Davos, Switzerland, December, 1920.]

[Translated by C. LeRoy Meisinger.]

SYNOPSIS.

The pyranometer of A. Ångström has been combined, at the observatory of Prof. Dorno, at Davos, with a recording device consisting of lamp, galvanometer, and a rotating photographic film, upon which the galvanometer deflection is recorded. In this way records are obtained of the total heat radiation from sun and sky upon a horizontal surface at all times of day, and from this record the daily sums are easily computed. In the present paper the recording method is described, the sources of error are discussed, and finally the results from the records at Davos are presented and compared with results of measurements at Washington and with the records of the brightness previously obtained by Prof. Dorno.

Concerning the instrument.—A. Ångström's pyranometer has been described in an earlier number of the REVIEW.[2] The J. L. Rose Co., of Upsala, has, since that time, furnished a somewhat smaller type of this instrument in a slightly simpler form, without the leveling screw, level, or the screen mechanism for cutting off the sun. The constant of the instrument, furnished by the manufacturers, may be quite accurately checked, by first exposing the strips to the sun and sky, and then to the sky alone. These observations combined with a simultaneously made pyrheliometric determination of the solar radiation intensity, I, and the solar altitude, h, enable one to determine the constant by means of the fundamental formula $R=ci^2$, (where R is the radiation intensity, i the strength of the heating current, and c the constant), and the known relation, $c=\frac{I \sin h}{i^2_1-i^2_2}$, ($i^1$ and i^2 being the two heating currents in the two exposures mentioned above).

[1] Published simultaneously in the *Meteorologische Zeitschrift*, Feb., 1921.
[2] Ångström, Anders: A new instrument for measuring sky radiation. MO. WEATHER REV. November, 1919, 47: 795-797.

Small variations of this constant are to be expected since the absorptive power of the black platinum strip and the reflective power of the magnesium oxide are not absolutely uniform for the entire length of the spectrum of the sun and sky. The constant evaluated in this way for the Davos instrument, 12.93, compares favorably with similar measurements on the larger type of instrument, which, in another manner, was found to be 8.61.[2] The instrument proves to be very reliable and uniform neglecting a few very easily removed deficiencies. Numerous trials have been made at the Davos Observatory and a 10-day comparison was made between the two specimen instruments under very favorable conditions. This comparison was made during the period of November 8 to 17, 1920, the registering instrument proving very practicable. In conjunction with these comparison measurements, records were taken over two November and two December decades. The registration apparatus is described in the January, 1921, *Meteorologische Zeitschrift.* With its application the compensation procedure will naturally be neglected, only the swing of very sensitive galvanometers will register photographically; auxiliary tension and damping resistance will not be considered. Both poles of the thermoelement are grounded, but between one of these and the earth the galvanometer is placed and the necessary resistance introduced to diminish the current. On this arrangement, a galvanometer throw of 1 mm. indicates 0.005 gr. cal./min. cm.^{2}; a very small correction may possibly be applied to this value, while the constant, c, as has already been mentioned, awaits a more absolute determination, because, further, the relations with larger solar altitudes will be more reliable, and because, finally, the quality of the

bell-glass leaves something to be desired. Even with winter solar altitudes, the width of the photographic paper upon which the galvanometer deflection is recorded, 14.5 cm., does not suffice, and the amplitude of the throw must be reduced by about one-half by the insertion of 1000 ohms resistance, and, occasionally, at the beginning of registration about the middle of November, it is necessary to insert 2000 ohms; the corresponding readings must then be multiplied by the factor 3.05. The zero line is determined in the morning, at noon, and in the evening, by breaking the circuit for ten minutes.

If the instrument is screened off from the sun and sky, the record is only slightly influenced by small variations (only up to 1 mm.) due to the long-wave radiation of the bell-glass and cap, and it appears that warming elevates the line, and cooling lowers it. The evaluation of the curves is managed in the same manner as the evaluation of brightness curves.

The small remaining residuals have three causes: (1) the bell-glass as it has been furnished up to the present is not satisfactorily homogeneous and it even has bubbles of such size that they can be seen readily by the shadows they cast.[3] By exposing the bell-glass and the strips in exactly the same orientation to the solar beam, one obtains quite similar galvanometer swings; but this is not exactly the case if the orientation of the instrument is changed. During the daily registration, errors originate if the instrument remains in a fixed position, and these errors can amount to as much as 4.5 per cent. This error can be reduced to a minimum. (2) With a horizontal exposure of the strips and a very low sun, which, of course, causes the rays to fall in a very slanting manner, there is some radiation which falls between the strips on or in the vicinity of the thermoelements. This also needs improvement, even though a perfect remedy may not be possible. (3) The instrument possesses a certain lag, and does not follow the variations of intensity so quickly as does the photoelectric method. The cause of this is found in the heat capacity of the receiving surface and in the fact that the heat is not transferred instantaneously to the thermo-elements. When one makes use of the chief superiority of this instrument, its registering capability, then the lag becomes important in consequence of the relatively large induction forces opposing the small electromotive force of the thermoelement. By means of alternate shading and exposing, it is discovered that in less than the galvanometer's period (scarcely ten seconds) at least 63 per cent of the intensity will be registered, the difference between the incident radiation and the pyranometer reading will be reduced in less than 10 seconds to at least the e^{-1}th part—a definition of the lag which has been applied by Eric R. Miller to his testing of the Callendar recorded and which seems very adequate.[4] The result follows the form of a very steep exponential curve, only about the last seventh of the intensity remaining after about 1½ minutes after screening the instrument. Through this lag, with continuous automatic registration, there originates a small smoothing out of the curve which is hardly apparent on the normal scale (16 mm. to 1 hour) but which is shown by a comparison with the photoelectric record. This third small residual error can hardly be eliminated or corrected.

[3] Later, the Zeiss Co. has furnished for use with the instrument, bell-glasses which have proved almost entirely free from the disadvantages mentioned above.—*A. Å.*

[4] MO. WEATHER REV., June, 1920, 48: 346.

Results.—As an example of a day's radiation of sun and sky received on a horizontal surface, the curve of November 26, 1920, is offered. On this day there was delicate bright cirro-stratus (cloudiness 3–6), the brightness of the sun varying between bright to very bright. At 9:28 a. m., the sun rose over the mountain, and at 3:12 p. m., disappeared behind the mountain; between 9:48 a. m. and 2:52 p. m., 1,000 ohms were inserted in the circuit, and the circuit broken from 7:57 a. m. to 8:03 a. m., 1:31 p. m. to 1:37 p. m. and 5:20 p. m. to 5:35 p. m. In figure 1 it is seen that on the one hand from 8:00 to 9:28

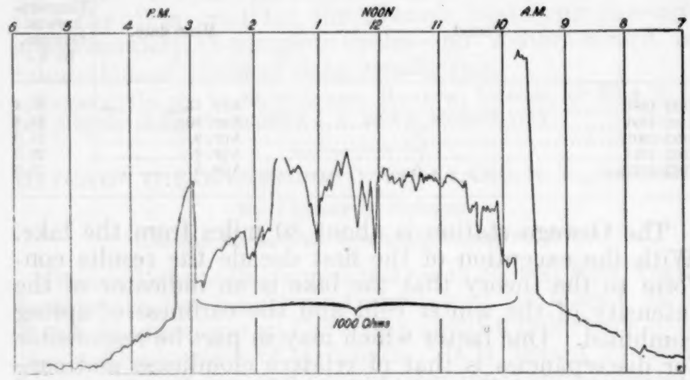

FIG. 1.—Radiation of sun and sky received on a horizontal surface recorded at Davos, Switzerland, on Nov. 26, 1920.

a. m. and from 3:00 to 3:12 p. m., when the resistance was not in, there are scarcely any vibrations in the line; and, on the other hand, during the day, with the 1,000 ohms in, there are sharply marked variations corresponding to the temporary obscurations of the sun. These facts indicate the trustworthiness of the instrument.

In Table 1 are given, in gram calories per square centimeter for the two last decades of November and the two first decades of December, the mean hourly totals (true solar time), the daily sums, as well as the absolute and mean intensity maxima, and for noon, the mean, maximum, and minimum intensity. All of these data are given (1) for all days, and (2) for clear or nearly clear days.

Let us compare next the observations of radiation of a horizontal surface from the sun alone made during the years 1908–1910 on absolutely clear days with the daily sum by the present method. For example, compare November 17, 1920 (neglecting the time the sun was behind the mountain) with the mean of November 15 from 1908 to 1910 (Table 4 of "Studie"[5]), increasing the daily sum by 3.5 per cent in order to bring them to the height of the Smithsonian scale, and calculating 0.04 gram calories per square centimeter per minute for the diffuse sky radiation with a mean solar altitude of 10°. Then one obtains for the pyranometer measurement 185 calories and for the computed values for 1908–1910, 178 calories, the former case being 4 per cent greater than the latter, which is about the same amount as the sun radiation in November, 1920, was in excess of that in 1908–1910. For a similar comparison for December, the result is somewhat different, but is satisfactory. The bright snow cover after December 1, on the mountain heights, increased the diffused radiation by over 60 per cent.

[5] "*Studie über Licht und Luft des Hochgebirges,*" Vieweg, 1911.

TABLE 1.—*Hourly and daily totals, maxima and minima of sun and sky radiation on a horizontal surface, in gram calories per cm.² per min.*

I. ALL DAYS.

1920.	(True solar time) hours ending at— 8	9	10	11	Noon.	1	2	3	4	5	Total	Intensity maximum. Absolute	Intensity maximum. Mean.	Intensity at 12 o'clock (noon) Mean.	Maximum.	Minimum.	Number of normal days.
Nov., 2d decade........	1.22	3.64	19.12	34.80	36.46	34.97	29.66	19.55	6.69	1.34	187.5	1.001	0.700	0.607	0.713	0.435	......
Nov., 3d decade........	1.55	4.46	15.41	26.72	29.90	26.73	22.75	24.59	5.71	1.24	149.1	0.695	0.596	0.537	0.648	0.410	......
Dec., 1st decade........	1.10	3.87	10.80	19.99	25.04	25.74	20.23	13.96	4.57	0.66	126.0	0.754	0.532	0.452	0.748	0.181	......
Dec., 2d decade........	0.96	4.07	13.26	27.55	32.30	33.45	25.11	16.05	5.29	0.89	158.9	0.996	0.702	0.584	0.838	0.332	......

II. CLEAR OR PARTLY CLOUDY DAYS.

1920.	8	9	10	11	Noon.	1	2	3	4	5	Total	Absolute	Mean.	Mean.	Maximum.	Minimum.	Number of normal days.
Nov., 2d decade........	1.02	2.81	20.98	38.27	41.33	38.48	32.45	22.22	7.84	1.49	206.9	0.742	0.698	0.675	0.713	0.625	6
Nov., 3d decade........	1.35	3.42	18.24	32.19	36.27	34.17	29.67	19.59	6.18	1.53	182.6	0.634	0.608	0.509	0.615	0.582	2
Dec., 1st decade........	1.26	3.94	13.94	28.78	36.28	38.94	26.64	19.74	5.98	0.94	176.4	0.754	0.751	0.700	0.748	0.632	3
Dec., 2d decade........	0.74	3.41	12.50	29.97	33.96	33.38	26.24	18.12	5.19	1.13	164.6	0.661	0.643	0.616	0.635	0.600	4

Under the influence of cloudiness, the radiation received on a horizontal surface was diminished during the two November decades from 389.5 calories to 366.6 calories, or a decrease of 13.6 per cent. (This represents observations during 71 per cent of the total possible duration of sunshine, as determined by the topographical features around Davos.) Table 6 of the "Studie" shows that the direct solar radiation a on a horizontal surface was decreased by cloudiness in November in the average by 59.4 per cent. The calculation of this table is based, however, upon the 10-year means (1899–1908) of records of the Campbell-Stokes sunshine recorder, but the sunny November of 1920 surpassed these means by fully 22 per cent (130 hours as compared with 107 hours). In view of this rather crude calculation, it appears that the radiation value as determined by the solar intensity measured in a clear sky and from the duration of sunshine as measured by the Campbell-Stokes instrument does not disagree widely with the real one; that even the mean total of radiation from clouds is nearly compensated by the diminished brightness of the sun as recorded by the sunshine recorder. This previous experience, which extended only to low solar angles and winter cloudiness, demonstrates that for radiation we can count with similar conditions as for brightness. The total brightness is less dependent upon the brightness of the sun at low solar angles than at high; with low and bright sun, the effect of clouds goes in the direction of increasing the radiation by 10 to 20 per cent. Clouds are most effective when near the sun with high altitude angles. Maxima (an increase up to 65 per cent) occur when the sun suddenly breaks through an opening in high white stratus clouds. With hazy sun (S_1) and bright stratus, the values are quite similar to the normal; with very hazy sun it reaches about four-fifths of normal; with very hazy sun in a valley filled with low, light gray clouds at an altitude of about 100 meters, the value becomes two-thirds, with average snowfall from nimbus, the value is one-half to one-third of the normal. The value is thus less with low clouds than with the high ones, and they are not identical with other conditions under the high valley conditions of Switzerland.

Excluding the sun and the bright sky immediately adjoining the sun, the radiation received from the sky on a horizontal surface amounts to 0.09 with the solar altitude 25°; to 0.08 at 20°; to 0.04 at 10°; and to 0.02 at 0°, all values being gram calories per square centimeter per minute. Even after sunset, the diffuse sky radiation is of measurable intensity. With the appearance of white cumuli or bright stratus at bright or medium bright sun an increase to double or three-fold the normal value is measured, while with very hazy sun, it amounts to only 15 to 30 per cent. With a clear sky, the nocturnal long-wave radiation of the earth at Davos[6] amounts to—

Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.
0.182	0.178	0.183	0.180	0.205	0.216	0.185	0.183

these being mean values from twilight to twilight in gram calories per square centimeter per minute. The assumption that these values of the long-wave earth radiation are also applicable to the day time is hardly to be doubted, as was shown by the observations of A. Ångström at Avike, in Sweden, during the solar eclipse of August 21, 1914.[7] While the radiation of short-wave length of the clear day sky in the high mountains in winter is only a small per cent of the long-wave outgoing heat radiation, there is a continuous stream of heat moving from the earth to the sky, and this effect is probably also in the average the same in the summer time. The reflection from freshly fallen snow on the mountain slopes amounts, at a solar elevation of 20°, to 69 per cent of the normal sky radiation with a clear sky; this value was determined photometrically in the years 1908–1910 to be about 50 per cent on the average. ("Studie," p. 47.)

For more than 10 years at Washington means of the sun and sky radiation falling on a horiziontal surface, as recorded by the Callendar pyrheliometer, have been measured.[8] These values in comparison with those at Davos show good agreement. For instance, with 27° solar altitude the value of 0.68 gram calories per square centimeter per minute was obtained at Washington on December 22 and at Davos on November 10. And at Madison, Wis., which lies in latitude 43° 5′ as compared with Davos at latitude 46° 48′, and at an elevation of 300 meters as compared with 1,600 meters at Davos, the November mean of eight years of observation scarcely departs from that observed at Davos in the second November decade, so far as the sun at Davos is not obscured morning and evening by mountains. The result is unexpected. Since the solar intensity in high mountains is usually in excess of that of lower elevations (in the foregoing example the solar intensity at Washington was 1.18 and that at Davos 1.38), it must be

[6] MO. WEATHER REV., June, 1920, 48: 349. This is an extended comparison between the Tulipan instrument and pyrgeometer, which shows that the simple Tulipan instrument can be put to the use of determining the nocturnal radiation and at the same time the conditions of cloudiness during the night.

[7] Meteorologische Zeitschrift, 1916, p. 58.

[8] Miller, Eric R.: Some characteristics of the Callendar pyrheliometer. MO. WEATHER REV., June, 1920, 48: 344–347.

concluded either that the diffuse sky radiation at a given place is extremely important (ratio of vertical component of solar radiation to that from sun plus sky was in Washington 0.80, in Davos 0.92) or that the difference lies in instrumental errors, of which a clue might be found in the above-mentioned investigation by Eric R. Miller of the Callendar recorder.

A comparison between the curves of heat radiation and the brightness curves given in the January, 1921, issue of the *Meteorologische Zeitschrift* shows, as one might expect, that the former has a smaller amplitude than the latter. As a rough approximation, to illustrate, the brightness intensity increases in the ratio 1 :1.5 :2 with solar altitudes of 15, 20, and 25°, while the heat radiation increases in the ratio 1 :1.35 :1.5. This point will be discussed later.

In spite of the three small residual errors discussed above, the instrument has proved itself to be a great advance and will probably gain general use. It will serve a useful purpose in many investigations which are of great importance to meteorological advances and which depend upon the interchange of heat between the earth, sun, atmosphere, and space. This will depend also upon a correct understanding of the relations of nocturnal radiation to temperature and humidity and to the type and amount of clouds. Furthermore, the instrument will serve to give the values of "vorderlicht" and "unterlicht" (vertical surface, and horizontal surface exposed downward) in calorie measurements; it will give data on the relations between altitude and optical purity and radiation; and if a suitable bell-glass is perfected it will extend investigations on single parts of the spectrum. The results obtained with this instrument may also be a valuable check on the results obtained with other differently constructed instruments; in order that we may be sure of an experimental result, it seems important that it should appear on the basis of different methods agreeing with one another.

NOCTURNAL TEMPERATURE INVERSIONS IN OREGON AND CALIFORNIA.

By FLOYD D. YOUNG, Meteorologist.

[Weather Bureau Office, Portland, Oreg., Jan. 5, 1921.]

SYNOPSIS.

Not enough attention has been paid in the past to locating crops subject to damage by frost on the more frost-free hillsides; and at the present day the phenomenon of nocturnal temperature inversion is not well understood by most fruit growers. Orchards set out 20 years ago in some of the coldest sections in several fruit districts on the Pacific coast are still being operated at a loss, while others have been removed only during the last two or three years. Detailed records of nocturnal temperature differences on slopes, covering entire frost seasons, are scarce.

Observations of nocturnal temperature inversions, made at Pomona, Calif., and Medford, Oreg., during the frost seasons of 1918, 1919, and 1920, are given in detail and discussed in this paper. Inversions at Pomona during the winter are compared with those at Medford during the spring. Differences in minimum temperature as great as 28° F. were observed between stations at the base and 225 feet above the base, on a hillside at Pomona.

The greatest inversions occur on clear, calm nights, following warm days. The duration of the minimum temperature on the hillside is usually much shorter than on the valley floor below, on account of large fluctuations in temperature during the night on the hillside.

On every hill where observations were made, the data indicate that on clear, calm nights the top of the hill is colder than points on the hillside some distance below.

The temporary vertical distribution of temperature found in the atmosphere over a plain or a valley floor on clear, calm nights, wherein the air temperature increases from the ground up to a height of from 100 to 1,500 feet above the ground, is called "nocturnal temperature inversion."

The steps in the development of a nocturnal temperature inversion may be summarized briefly as follows:

During a clear, calm day the temperature of the ground surface is raised through heat received by radiation from the sun, and the air in contact with the ground is warmed by conduction. This warmed air is forced upward and replaced by cooler and denser air from near by or above, and a circulation is established, which continues as long as the ground surface is warmer than the air in contact with it. Near sunset the air up to a height of a thousand feet or more is very nearly in adiabatic equilibrium.

After the sun goes down, the surface of the ground loses heat rapidly by radiation to the sky and its temperature soon falls below that of the air in contact with it. The surface air cools through conduction of heat into the colder ground, and its density becomes increasingly greater. Its increased density tends to keep it in contact with the ground, where it continues to grow colder and colder throughout the night. As air is a poor conductor and radiator of heat, the temperature of the air a few hundred feet above the ground falls much more slowly, and by sunrise a considerable difference in temperature has developed between the air at the surface of the ground and that a few hundred feet above the ground.

In the case of a valley, with fairly steep slopes on either side, the minimum temperature on a frosty night is likely to be much lower on the valley floor than at points on the hillside, the highest minimum temperature occurring at a height of from 200 to 1,500 feet above the valley floor.

A knowledge of the average and extreme differences in temperature between different portions of the hillsides and the valley floor is of great practical value in deciding where certain crops will be grown. If this information is available, crops most susceptible to damage by frost can be planted at the level on the hillside where the highest minimum temperature is found most frequently, and the colder locations on the floor of the valley can be utilized to grow more frost-resistant crops.

A single season's observations may be misleading, as the nocturnal temperature inversion varies from year to year in the same way that one season's weather differs from another's. At long intervals "freezes" are likely to occur, in which low temperatures are accompanied by high winds, and crops on the hillsides suffer as much, or even more, damage than those on the valley floor.

Temperature inversion [1] also plays an important part in the protection of crops by orchard heating; the extent of the inversion and the amount of wind largely determine what the efficiency of the heaters will be on a given night. A strong wind will prevent the development of a marked temperature inversion by keeping the air at different levels thoroughly mixed; in localities where low temperatures during the growing season usually occur with little air movement, orchard heating can be practiced with greater success than in districts where low temperatures are often accompanied by high winds.

In most of the orchard districts in the Pacific coast States, either through lack of knowledge or through dis-

[1] See Humphreys, W. J.: Frost Protection. MO. WEATHER REV., October, 1914, 42: 562-564.

regard of the facts regarding temperature differences between hillside and valley floor, orchards were planted in some of the coldest locations in each section. These were generally brought into bearing at considerable expense before the discovery was made that low temperatures caused the loss of the greater portion of the crop nearly every year. In many cases these orchards have been cared for year after year, passing from hand to hand as each new owner, in turn, discovered that they could not be operated except at a loss. Most of them are now in the process of removal, but they have left a large number of people richer in experience and poorer in material resources.

Of course, this applies only to orchards in the most unfavorable locations; in many cases orchards on the valley floors have been operated with marked success, damage by frost either being prevented by artificial means, or the amount of loss in the long run not being great enough to make the business unprofitable.

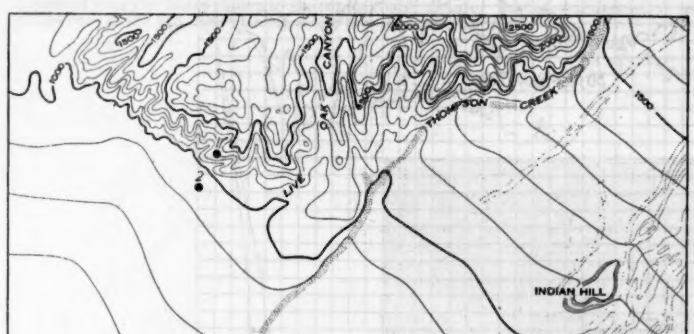

FIG. 1.—Topographic map of the Pomona Valley, Calif., showing locations of temperature survey stations and instrument tower. Contour interval 50 feet.

Factors other than the relative amount of loss through damage by frost, such as availability of water for irrigation, the character of the soil, difficulties in cultivating and irrigating steep slopes, must be taken into consideration in selecting a location for an orchard; if all available slopes in the fruit districts were set to orchards and all the orchards on the lowlands were removed, the acreage in fruit would probably fall far short of the present mark. There also seems to be considerable basis for the contention that citrus fruit grown in districts where frosts seldom occur is of a poorer quality than that grown where temperatures near the limit of endurance for the variety are of frequent occurence during the winter.

HILLSIDE AND VALLEY TEMPERATURES AT POMONA, CALIF.

During the winter of 1917–18 temperature survey stations were established in a line across the northern half of the Pomona Valley, in Southern California, for the purpose of obtaining information regarding local temperature inversions. The locations of these stations are shown in figure 1. (See also figure 2.) Maximum and minimum thermometers were exposed at each station in fruit region instrument shelters,[2] the instruments at all stations being about 4½ feet above the ground. A seven-day thermograph was operated at station 1, and 29-hour thermographs at stations 7, 8 and 9. Thermometers were read daily except at station 1, which was visited at least once each week, and oftener when practicable.

Minimum temperatures at stations 1, 2, 7, 8, and 9, for the 29 clear nights of the frost season of 1917–18 are given in table 1. A profile of the valley, showing the locations of the stations and the average minimum temperature at each, is shown in the MONTHLY WEATHER REVIEW [3] for August, 1920. The greatest differences in minimum temperature during the period from January 6 to February 16, 1918, were 22.0° F. on February 4 between stations 1 and 2 (170 feet), 21.8° F. on February 10 between stations 8 and 9 (125 feet), and 21.9° F. on February 10 between stations 7 and 9 (250 feet). On January 1, 1918, before station 1 had been established, the minimum temperature at station 7 was 24.0° F. higher than the minimum at station 9.

During the 1918–19 frost season stations were established at intervals of 50 feet vertical elevation, from the summit of San Jose Hill (station 7, figure 1) down to an elevation of 125 feet above the base station. (See figure 2.) From this point to the base stations were established for every 25 feet vertical elevation. A profile of this hillside, showing the location of each station, with the average minimum temperatures for the 45 clear nights of the season, and the actual minimum temperatures recorded on the night of January 5–6, 1919, is shown in the MONTHLY WEATHER REVIEW [3] for August, 1920.

Daily minimum temperatures at all stations on this hillside for all clear nights during the 1918–19 frost season are given in Table 2.

The greatest difference in minimum temperature between the base and 275-foot stations was 25.7° F. on January 8, while the greatest difference between the base and 225-foot stations was 28.0° F. on January 6. The minimum temperature at the summit was higher than the minimum at the 225-foot station on only one clear night during the season; and on that date it was only 0.1° F. higher. The average minimum temperature for all clear nights during the season was 1.6° F. higher at the 225-foot station than at the summit, and the average minimum temperature 150 feet below the summit was higher than at the summit.

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[2] For a description of this shelter see the MO. WEATHER REV., December, 1920, 48: 709–710.

[3] Young, F. D.: Effect of topography on temperature distribution in Southern California. MO. WEATHER REV., August, 1920; 48: 462.

As the minimum temperature was practically never reached at all stations simultaneously, the inversion at a given hour during the night was often greater or less than the difference between the minimum temperatures.

Enlarged and corrected thermograms from stations at the base and on the slope of San Jose Hill, for two nights, with large and slight temperature inversions, respectively, are shown in figures 3 and 4. It will be noted that the fall in temperature at the lower stations is fairly steady, while there are large fluctuations in temperature at the stations on the slope. Because of these rapid changes, which occurred at the higher stations on every clear night, the duration of the minimum temperature was usually much longer at the base stations than at those on the slope. The minimum temperatures alone, therefore, do not indicate the amount of damage sustained by crops at different elevations on a given night.

Blair [4] noted similar fluctuations in temperature during the night at stations on the slope of Mount Weather.

[4] Blair, W. R.: Five-year summary of free air data; *Bull. Mt. Weather Observatory*, 1913; 6: 122-123.

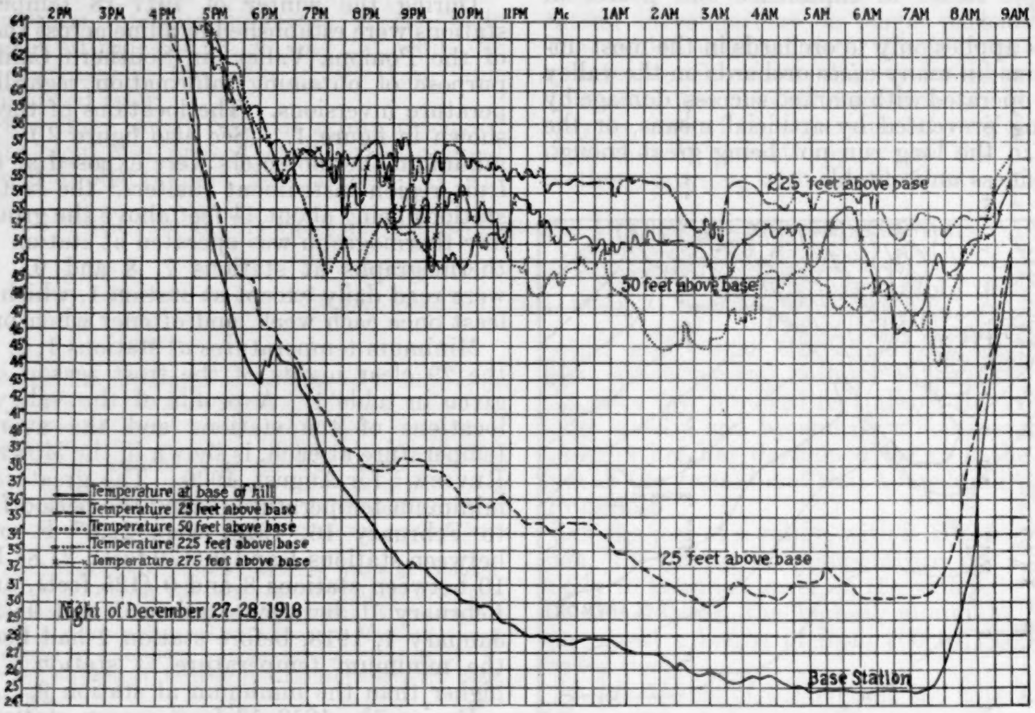

FIG. 3.—Corrected thermograms from stations at the base, and 25, 50, 225, and 275 feet above the base of the south slope of San Jose Hill (see fig. 1) on a night with large temperature inversion. A view of the slope on which these records were obtained is shown in fig. 2.

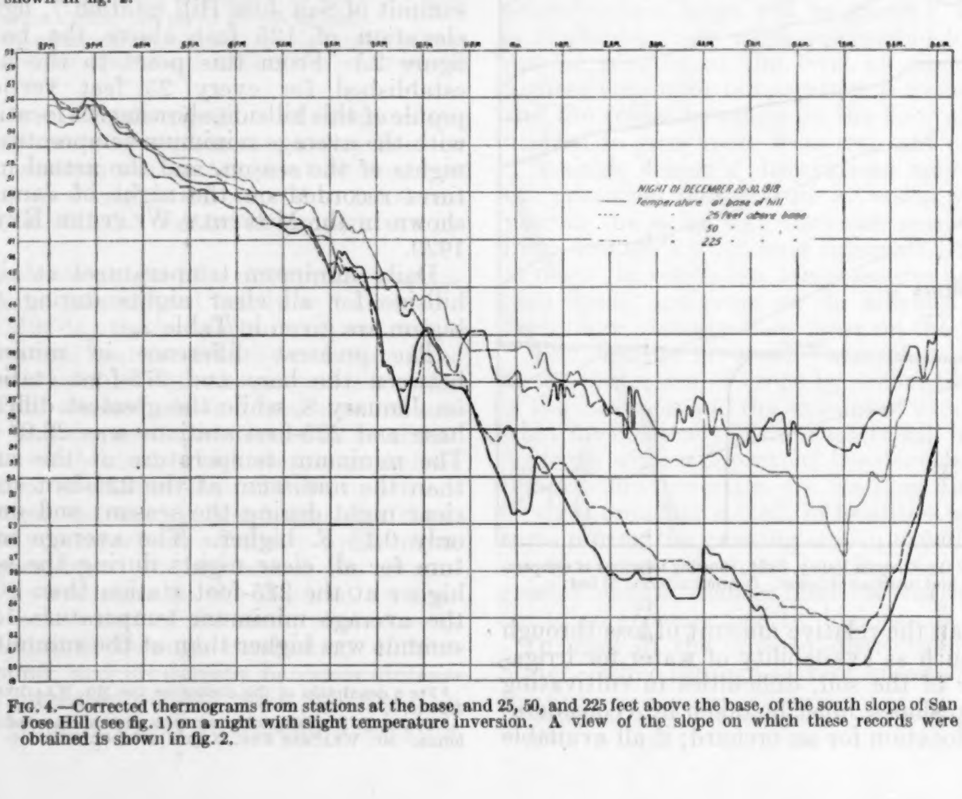

FIG. 4.—Corrected thermograms from stations at the base, and 25, 50, and 225 feet above the base, of the south slope of San Jose Hill (see fig. 1) on a night with slight temperature inversion. A view of the slope on which these records were obtained is shown in fig. 2.

FIG. 2.—View of the Pomona Valley, looking southward from station 7. Station 8 is located near the house shown in the center of the picture. Station 9 is located at the base of the hill, near the left of the picture. (See fig. 1.)

FIG. 7.—View from Coker Butte (station 1, fig. 9), looking westward across the valley. The wireless towers can be seen in the background at the right. Stations 6, 7, and 8 (fig. 9) lie in a straight line beyond the wireless towers.

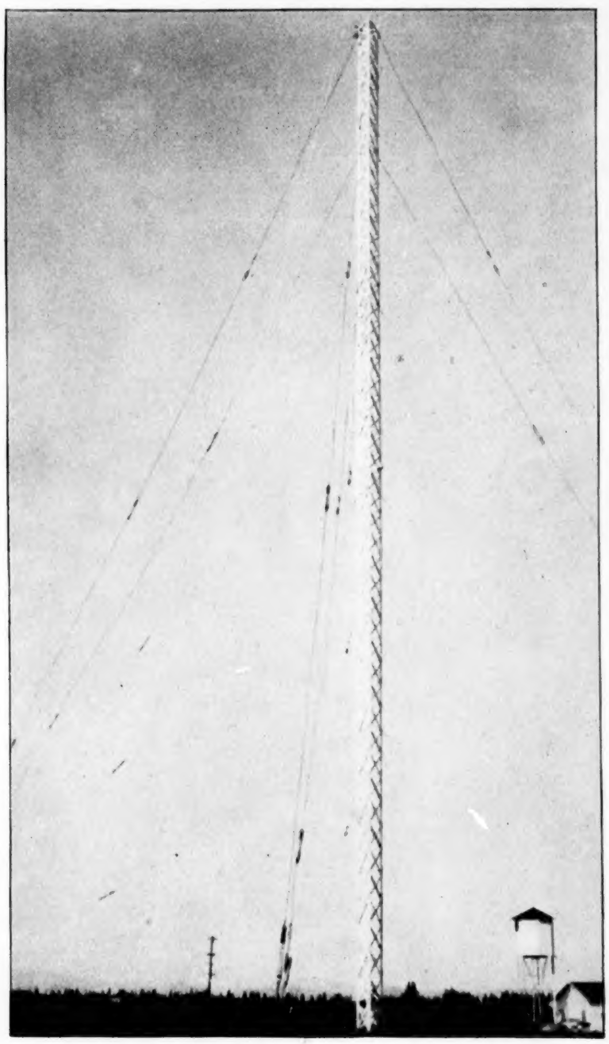

FIG. 8.—Three hundred-foot wireless tower, near Medford, Oreg., used in making temperature inversion studies (see fig. 9). Photograph by J. Cecil Alter.

From an examination of table 2, it will be noted that the greater part of the inversion is in the first 50 feet above the base of the hill; on most nights there was a difference of only a few degrees between the minimum temperatures at the 50-foot and 225-foot stations. These and other observations show that on clear, calm nights an extremely thin stratum of cold air covers the entire valley floor, with much warmer air only 50 to 100 feet above.

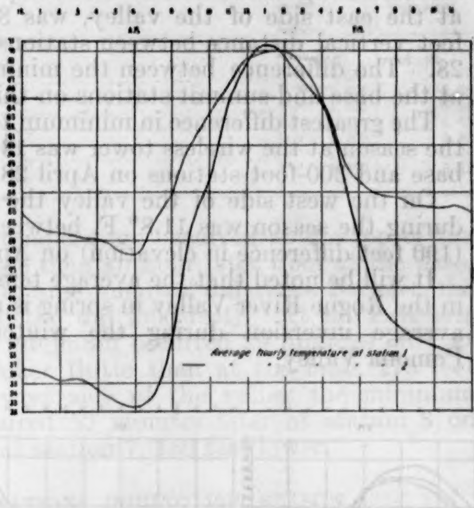

FIG. 5.—Average diurnal variation in temperature at stations 1 and 2 (fig. 1) for 12 clear days during January and February, 1918.

This sharp inversion of temperature is probably due to abnormally low valley temperatures. Thermograms from the hillside stations do not show the lower maxima usually found at hillside stations. The average maximum temperature for 21 clear days during the months of December, 1917, January and February, 1918, is 3° F. higher at station 8 and 2° F. higher at station 7, than the average maximum for the same dates at station 9, 250 feet below the summit. The average diurnal variation in temperature at hill and valley stations during 1918 is shown in figures 5 and 6.

The humidity is generally low in the Pomona Valley, often extremely so when the wind is blowing from the east or northeast. Relative humidities as low as 5 per cent and dewpoints as low as 3° F. have been indicated by carefully made sling psychrometer readings. With little moisture in the air to retard nocturnal radiation, the temperature in the valley falls rapidly after the sun goes down. The closely planted citrus trees, with their heavy foliage, offer considerable obstruction to surface air movement and probably are also somewhat effective in lowering the maximum temperature within the orchards through evaporation from the leaf surfaces. The dark foliage probably radiates heat during the night at a more rapid rate than would the lighter-colored ground, with no covering.

SIDE AND VALLEY TEMPERATURES AT MEDFORD, OREG.

Observations of nocturnal differences in temperature between stations at the bases and on the slopes of hills in the Rogue River Valley were carried on during the spring frost seasons of 1918 and 1919. During the 1918 season stations were established in a line across the valley, from the summit of Coker Butte (elevation, 1,650 feet) on the east (see fig. 7), to a point on the foothills on the west side of the valley (elevation 1,450 feet). About half the distance between the base stations on either side instruments were exposed at the base and at elevations of 150 feet and 300 feet above the ground on a 300-foot wireless tower,[5] (see fig. 8), to measure the temperature inversion in the free air directly above the valley floor. The locations of all these stations are shown in figure 9.

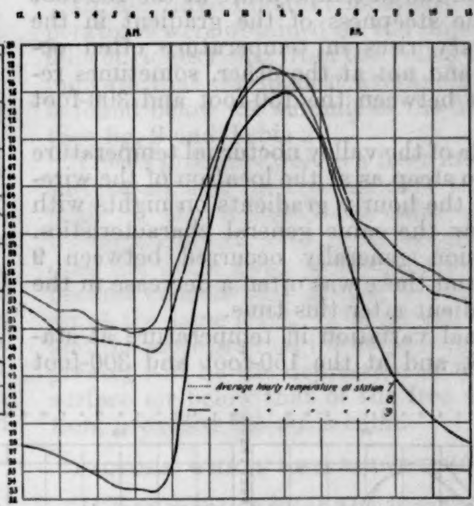

FIG. 6.—Average diurnal variation in temperature at stations 7, 8, and 9 (see fig. 1), for 21 clear days during January and February, 1918.

Minimum temperatures observed on clear nights during the spring frost season are given in Table 3. The average minimum temperatures for the season are entered at each station in figure 9.

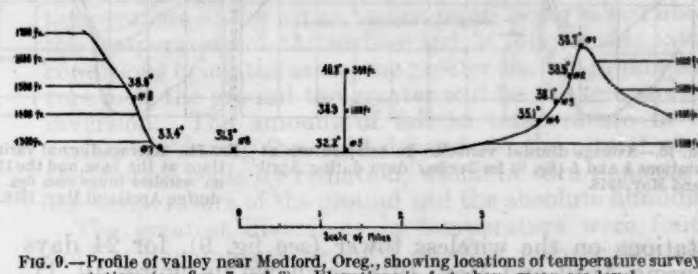

FIG. 9.—Profile of valley near Medford, Oreg., showing locations of temperature survey stations (see figs. 7 and 8). Elevations in feet above mean sea level.

The steepness of the nocturnal temperature gradient was slightly greater on the wireless tower than on the hillsides on either side of the valley, probably because the free air gradients were more nearly approximated on the tower.

At Coker Butte, on the east side of the valley, the highest minimum temperatures were recorded at station 2, 100 feet below the summit, and at station 3, 200 feet below the summit, the average minimum temperature was only 0.6° F. less than at station 1, on the summit.

Minimum temperatures at stations 8 and 3, at the same elevations but on opposite sides of the valley, were generally very nearly the same, but the minimum at the 150-foot station on the wireless tower, 40 feet lower, averaged 1 degree higher. Minimum temperatures at the 300-foot station on the wireless tower averaged 1.9° F. higher than those at station 2, on the slope of Coker Butte and at practically the same altitude.

At the wireless tower the inversion was generally nearly all in the lower 150 feet. The temperature was usually higher at the base than at the 150-foot level until 6 p. m., or even later. Between 7 p. m. and 11 p. m. the tem-

[5] The first temperature observations on this tower were made in 1916 by J. Cecil Alter.

perature at the base fell rapidly, developing a steep gradient between the base and 150-foot stations. From this time until sunrise the temperature at the ground fell more slowly and there was no increase in the steepness of the gradient; in fact, the thickness of the layer of cold air often increased sufficiently between 11 p. m. and midnight to cause a rapid fall in temperature at the 150-foot station, reducing the steepness of the gradient in the lower air. Temporary rises in temperature often occurred at one level and not at the other, sometimes reversing the gradient between the 150-foot and 300-foot stations.

On the western side of the valley nocturnal temperature gradients were not so steep as at the location of the wireless tower, although the hourly gradients on nights with large inversions show the same general characteristics. The greatest inversion generally occurred between 9 p. m. and 11 p. m., and there was often a decrease in the steepness of the gradient after this time.

The average diurnal variation in temperature at stations 1, 5, 7, and 8, and at the 150-foot and 300-foot stations on the wireless tower (see fig. 9), for 24 days during April and May, 1918, is shown in figures 10, 11, and 12. The difference between free air temperatures over the valley floor (shown by the records obtained at the wireless tower) and those on the hillsides is shown graphically. On the east side of the valley the afternoon temperature is higher at the summit than at the valley station, while at the wireless tower the temperature is lower at the 300-foot station than at the base by almost double the adiabatic rate, from 8 a. m. until noon, the period when convection is most active.

The temperature at the base of the tower falls below the temperature at both the upper stations about 6 p. m., and the temperature at the 150-foot level falls below the temperature at the 300-foot level about 7 p. m.

On the west side of the valley the temperature at station 8 falls below that at both stations 6 and 7 about 1.30 p. m., and the temperature at the two lower stations does not fall below that at station 8 again until about 7 p. m. This is probably due to the fact that the sun's rays are almost parallel to the slope during the early part of the afternoon and that later the whole upper slope is shaded from the sun some time before insolation is cut off from the valley stations.

A comparison of figures 10, 11, and 12 with figures 5 and 6 brings out the great difference in diurnal changes in temperature at Medford and Pomona. The influence of the longer nights at Pomona is evident from the late occurrence of the minimum temperature and the earlier time of occurrence of the maximum temperature, as compared with Medford.

The greatest difference in minimum temperature observed during the season at the stations on Coker Butte, at the east side of the valley, was 8.9° F. in the 175 feet vertical distance between stations 2 and 4, on April 28. The difference between the minimum temperatures at the base and summit stations on this date was 8.2° F.

The greatest difference in minimum temperature during the season at the wireless tower was 13.4° F. between the base and 300-foot stations on April 28.

On the west side of the valley the greatest inversion during the season was 11.8° F. between stations 6 and 8 (190 feet difference in elevation) on April 19.

It will be noted that the average temperature inversion in the Rogue River Valley in spring is much less than the average inversion during the winter months in the Pomona Valley.

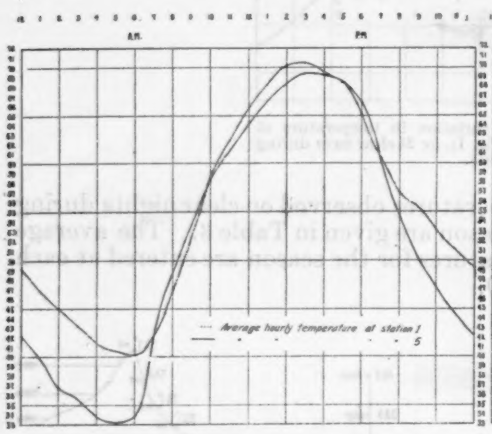

FIG. 10.—Average diurnal variation in temperature at stations 1 and 5 (fig. 9) for 24 clear days during April and May, 1918.

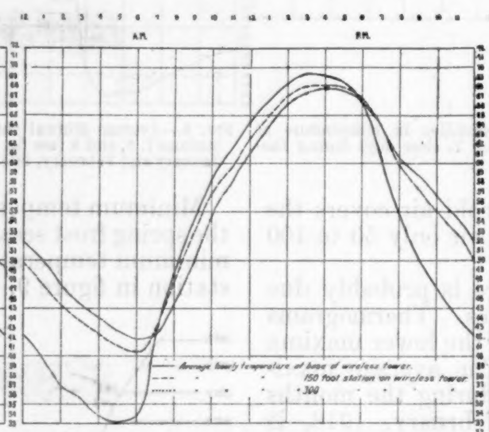

FIG. 11.—Average diurnal variation in temperature at stations at the base, and the 150-foot and 300-foot stations on wireless tower (see figs. 8 and 9) for 24 clear days during April and May, 1918.

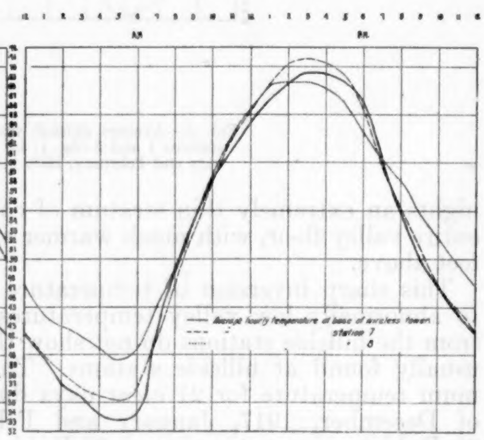

FIG. 12.—Average diurnal variation in temperature at stations 5, 7, and 8 (fig. 9) for 24 clear days during April and May, 1918.

MAXIMUM TEMPERATURES.

On clear days the maximum temperature at the 300-foot elevation on the wireless tower was from 3° to 6° F. lower than at the base, but there was seldom more than one or two degrees difference between the maxima at the 300-foot level and at the 150-foot level. The difference in maximum temperature in the 180 feet vertical distance between stations 7 and 8 varied from 2° to 5° F. on clear days, and on one day the difference was 6° F.

On the east side of the valley the maximum temperature at station 1, on the summit of Coker Butte, was consistently higher than the maximum at station 4 at the base of the hill, 275 feet below. Maximum temperatures at both stations 2 and 3 were the same or higher than those at station 4. This was probably due to the fact that stations 2 and 3 were located on the steep westward-facing slope, and station 1 on the summit, of Coker Butte. The convective currents caused by the rays of the afternoon sun, shining almost perpendicularly on the slope, probably were considerably warmer than the free air at the same elevation over the valley floor.

TIME OF OCCURRENCE OF MINIMUM TEMPERATURE.

The average time of occurrence of the minimum temperature on 20 clear nights during April and May, 1918,

at most of the hill and valley stations shown in figure 9 are given below. These data were taken from thermograph records, which were checked daily.

Stations.	Elevation (m. s. l.).	Average time of occurrence of minimum temperature.
	Feet.	*A. m.*
1	1,650	6.27
4	1,375	5.58
300 feet on tower	1,560	6.54
150 feet on tower	1,410	6.45
5 (base of tower)	1,260	5.50
8	1,450	6.24
7	1,270	5.32

The minimum temperature occurred at the top of the wireless tower more than an hour later than at the base, but there was only nine minutes' difference between the 150-foot level and the top (300 feet). At the east side of the valley the minimum occurred 29 minutes later at the summit of Coker Butte than at the base, 275 feet below. On the west side of the valley the minimum temperature occurred 52 minutes later at station 8 on the hillside than at station 7, 180 feet lower.

OBSERVATIONS DURING 1919 SEASON.

During the 1919 season a station was established on the summit, and two stations at the base of another hill in the Rogue River Valley, about five miles south of the wireless tower, where the 1918 observations were obtained. (See figs. 13 and 14.) A profile of this hill, showing the locations of the stations, is shown in figure 15. Minimum temperatures registered on clear nights during the spring frost season are shown in Table 4.

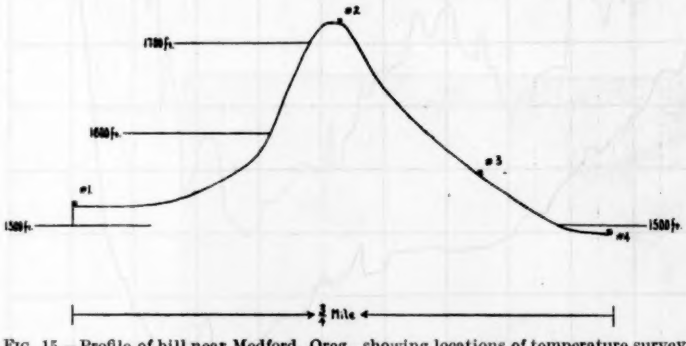

FIG. 15.—Profile of hill near Medford, Oreg., showing locations of temperature survey stations (see figs. 13 and 14). Elevations in feet above mean sea level.

Minimum temperatures on clear nights averaged only about 4° F. higher at the top of the hill than at the base, the difference in elevation being about 200 feet. This is in marked contrast to the temperature inversions observed at Pomona, where the average difference in 225 feet vertical elevation was 16.9° F.

The greatest difference between minimum temperatures at stations 1 and 2 during the season was 6.9° F., as against a maximum difference of 28° F. in 225 feet vertical elevation on San Jose Hill at Pomona.

The average difference in minimum temperature between the base station and station 3, 165 feet below the summit of the hill, was 4.1° F., only 0.2° F. less than the average difference in the 200 feet between stations 2 and 4. The greatest difference in minimum temperature on the hillside during the season was 7.1° F. between stations 1 and 3, on May 7. On this night the minimum temperature at the summit was 0.7° F. lower than the minimum at station 3, 165 feet below, on the hillside. While the average minimum at station 3 was not higher than the average minimum at station 2, on the summit, a station 50 feet or less below the summit probably would have shown a higher average minimum temperature on clear nights than the summit station.

In the three different locations where minimum temperatures were obtained on the slopes and tops of isolated hills or ridges rising from the valley floor the observations indicate that the highest average minimum temperature is found below the summit of the hill, on the steep slope. (See fig. 9 and Table 2.)

This is probably due to a freer interchange between the surface air and the free air over the valley on the slope than on the hilltop. On calm nights the air cooled through contact with a well-rounded hilltop probably does not drain away to lower levels until its density has become considerably greater than the density of the free air at the same level. The greater the area of the hilltop and the more gradual the slope near the highest point, the greater will be the depression of the temperature of the surface air below that of the free air at the same elevation, provided the air is calm.

FACTORS WHICH DETERMINE AMOUNT OF INVERSION.

It was mentioned at the beginning of this paper that about sunset on a clear, calm day the air for a considerable distance above the ground has nearly the temperature due to a complete mixing; that is, a decrease in temperature with elevation of about 1° F. per 188 feet. Since local nocturnal temperature inversions are caused by the lowering of the temperature of the surface air below that of the air at higher elevations[5] (not by the temperature of the air at higher levels being raised above the temperature of the surface air), it follows that, other conditions being the same, the greater the fall in temperature near the ground the greater will be the temperature inversion. The amount of fall in temperature in the surface air during the night depends on the rate at which the ground cools by radiation, which in turn depends on the temperature of the ground and the absolute humidity.

The greatest inversions in temperature were found, both at Pomona and Medford, on clear, calm nights when the dewpoint was low, following warm days. The smallest inversions on clear nights occurred when the dewpoint was high, and following days when the maximum temperature was relatively low. The wind was seldom strong enough on clear nights at either place to have much effect on the amount of inversion.

Since the greatest inversions occur following clear, still days, with high maximum temperature, the minimum temperatures on the valley floor on such nights are generally above the danger point. The most severe frosts usually occur on nights following cold, windy, and oftentimes cloudy, days. At such times the inversion is usually considerably less than the average.

The relation between the amount of nocturnal temperature inversion on a given night, and the maximum temperature of the preceding day, at Pomona, is shown in figure 16. Other factors influencing the amount of inversion, such as the amount of wind, cloudiness during a portion of the night, and the absolute humidity, are not represented in these graphs.

[5] H. J. Cox, in "Thermal Belts and Inversions of Temperature in the North Carolina Mountain Region" (MO. WEATHER REV., December, 1919; 47:879-880), states that when inversions were noted under cyclonic conditions, the temperature rose more rapidly at the summit than at the base, thus increasing the inversion. On the lower hills of the Pacific coast the approach of a cyclonic area usually prevents the development of temperature inversions through cloudiness and wind.

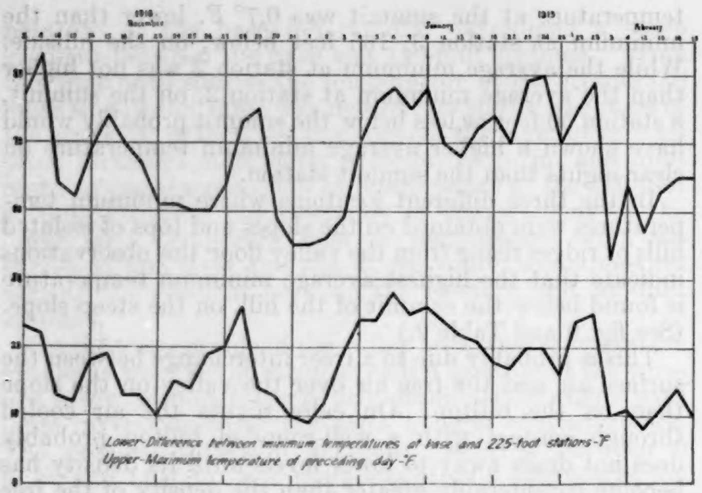

FIG. 16.—Relation of the amount of temperature inversion between the base and 225-foot stations on the slope of San Jose Hill, near Pomona, Calif. (see figs. 1 and 2), to the maximum temperature of the previous day at the base station. In nearly every case, lack of agreement between the trend of the data on individual dates is directly traceable to the influence of wind, clouds, or valley fog during the night.

A fairly accurate forecast of the amount of temperature inversion to be expected on the following night at Pomona, may be made as soon as the maximum temperature has occurred. The relation between the amount of temperature inversion and the daily range in temperature is still more marked.

The evening weather map preceding nights with large temperature inversions at Medford, practically always shows a stagnant condition, with slight pressure gradients. When the Arizona LOW is weak, or entirely absent, a large temperature inversion will practically always occur, provided the sky is clear during all or a part of the night. This may take place when there is no well-defined HIGH on the coast, but in this case there is no danger of frost. The greatest inversions usually occur when there is a large, weak HIGH central over northern California and southern Oregon, with no depression over Arizona, or one of only slight intensity.

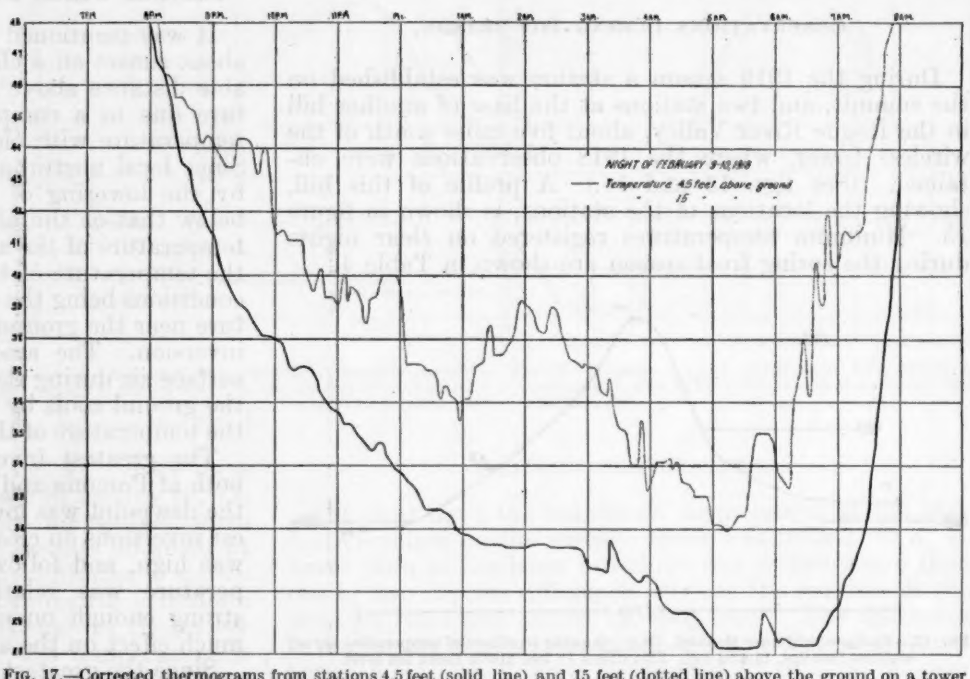

FIG. 17.—Corrected thermograms from stations 4.5 feet (solid line) and 15 feet (dotted line) above the ground on a tower in an orange grove near Pomona, Calif., for the night of February 9-10, 1918.

TEMPERATURE INVERSIONS NEAR THE VALLEY FLOOR.

Observations on the hillsides at Pomona indicated that the stratum of cold air near the ground on frosty nights was extremely thin. In order to obtain additional information as to the depth of this cold air near the ground, minimum thermometers and 29-hour thermographs were installed during the 1917–18 frost season, at elevations of 4½ and 15 feet above the ground on a 15-foot tower in an orange grove near the lowest portion of the valley. The ground within a radius of 1,000 feet from the tower was practically level, and the nearest steep slope was about a mile distant.

Minimum temperatures registered on this tower on 14 clear nights during the season are shown in Table 5. The average difference between minimum temperatures at the two stations on these nights was 1.6° F. The maximum difference was 3.7° on February 10. As the upper station was only slightly above the tops of the trees and the lower station was at about the height of the lowest fruit on the trees, minimum temperatures at the two levels indicate quite accurately the lowest air temperatures to which the fruit at the two elevations was subjected. The outside fruit near the top of the tree is less sheltered from the sky than the fruit lower down, and the higher rate of radiation probably offsets, to some extent, the advantage of a higher air temperature.

Differences between temperature conditions at the two elevations on individual nights are usually not adequately shown by the minimum temperatures alone. Fluctuations in temperature of 4° or more were common at the upper station, without corresponding changes at the lower station (see fig. 17). At times during the night differences as great as 7° in the 10.5 feet between the two stations were recorded.

During the 1918–19 season, records were obtained on a similar tower at practically the same location. Minimum thermometers were installed at elevations of 2, 5, 9, 12, and 15 feet above the ground. Wide, thin boards, placed directly over each instrument, were used to provide shelter from the sky and to protect them from dew and frost.

On 13 clear nights during January and February, 1919, the minimum temperature at the 15-foot elevation averaged 3.4° F. higher than the minimum at the 2-foot station. Differences on individual nights were as high as 6.5° F. Daily minimum temperatures for all elevations are given in Table 6. The duration of the minimum temperature near the tops of the trees was practically always much shorter than near the ground.

TEMPERATURE INVERSION ON 40-FOOT TOWER.

During February, 1919, the Pomona Frost Protective Association furnished funds for the erection of two towers, 30 and 40 feet high, respectively, for a study of orchard heating. Thermometers and 29-hour thermographs were placed in small shelters on both towers at 5-foot intervals, from 5 feet above the ground to the tops

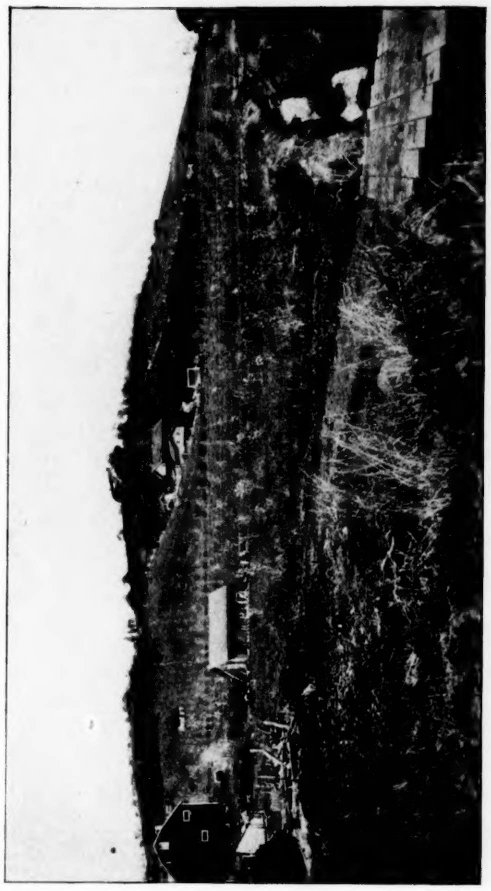

FIG. 13.—View of hill near Medford, Oreg., shown in figure 15, from station 1.

FIG. 14.—Rogue River Valley from summit of hill shown in figures 13 and 15. View taken from station 2.

FIG. 20.—View of 35-foot instrument tower near Medford, Oreg., on which minimum temperatures shown in Table 8 were obtained.

of the towers. The 40-foot tower was located in an orchard which was equipped with orchard heaters. Both towers were located on gently sloping ground, about half way between the base of the foothills and the lowest part of the valley (see fig. 1). Minimum temperatures at various elevations on the 40-foot tower during 13 clear nights in February, 1919, and 39 clear nights during the 1919–20 frost season, are given in Table 7. The difference in minimum temperature between the base and top of this tower was affected on a few nights by firing, but the records on the 30-foot check tower, around which no orchard heaters were burned, show that the influence of these brief periods of firing was slight and may be disregarded.

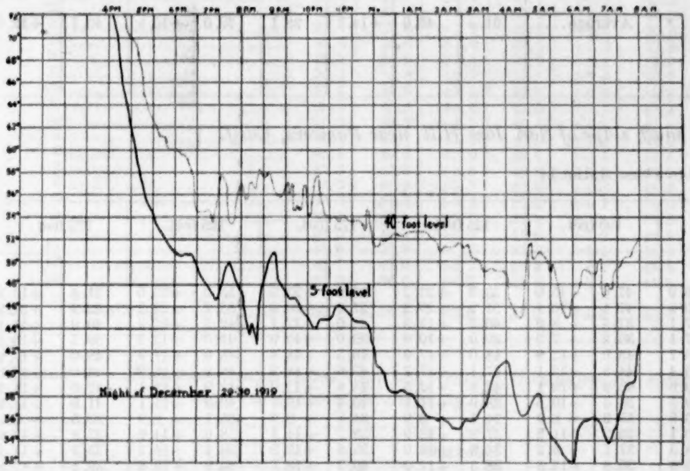

FIG. 18.—Corrected thermograms from 5-foot and 40-foot levels on a tower in an orange grove near Pomona, Calif., during the night of December 29–30, 1919. The temperature inversion on this night was above the average.

The average difference in minimum temperature in the 35 feet between the 5-foot station and top of the tower was 8.4° F.; slightly more than 1° for each 5 feet. The average rate of increase in minimum temperature from the 5-foot station to the 40-foot station, was quite uniform.

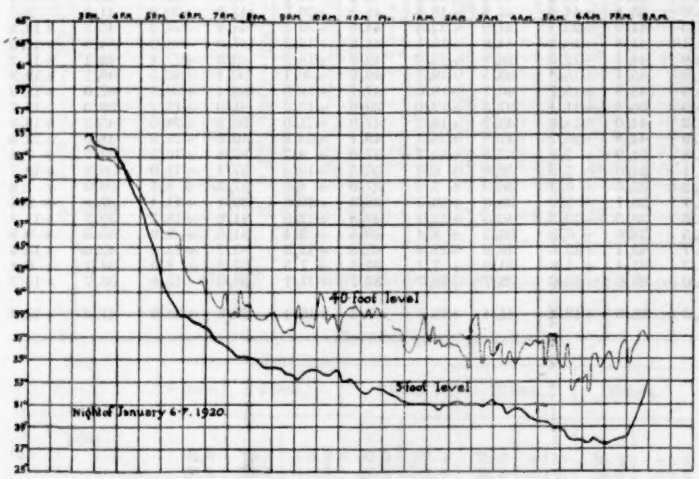

FIG. 19.—Corrected thermograms from 5-foot and 40-foot levels on a tower in an orange grove near Pomona, Calif., during the night of January 6–7, 1920. The temperature inversion on this night was below the average.

The greatest difference in minimum temperature was 15° F., on the morning of January 18, 1920. The maximum temperature of the preceding day was 85.4° F.

Corrected thermograms registered at the 5-foot and 40-foot stations on two nights, with large and small temperature inversions, respectively, are shown in figures 18 and 19.

OBSERVATIONS ON TOWERS AT MEDFORD.

In April, 1919, two 35-foot wooden towers were erected in pear orchards near Medford, Oreg., for use in the continuation of the orchard-heating investigations begun at Pomona (see fig. 20). These towers were located on gently sloping ground, near the lowest part of the upper valley. Minimum thermometers and 29-hour thermographs were installed in small shelters on these towers at elevations of 5, 15, 25, and 35 feet above the ground. Daily minimum temperatures at stations on the tower in the orchard which was not fired, for all clear nights during the 1919 and 1920 frost seasons, are given in Table 8.

The average difference in minimum temperature between the 5-foot and 35-foot stations was 4.2° F., slightly more than half the difference between the same stations on the Pomona tower. At Pomona differences between stations were quite uniform; at Medford the differences in minimum temperature between succeeding stations decreased from the base to the top of the tower. On several clear nights the minimum at the 35-foot level was lower than the minimum at the 25-foot level. The greatest difference in minimum temperature between the 5-foot and 35-foot stations at Medford was 6.8° F. The greatest difference between the same stations on the Pomona tower was 12° F.

CONCLUSION.

The average nocturnal temperature inversion on clear nights at Pomona during the winter months, is about double that at Medford in spring, probably on account of the lower humidity and greater daily range in temperature at Pomona. At both places the stratum of cold air over the valley floor on frosty nights is extremely thin.

The greatest inversions occur at both Pomona and Medford following warm days, and as a general rule the minimum temperature in the coldest section in the valley is not low enough to cause damage on such nights. On nights when extremely low temperatures are recorded on the lower ground, there is likely to be some damage on the hillsides, since on the coldest nights the temperature inversion is usually slight.

Observations on the 300-foot wireless tower, located on the valley floor near Medford, about equidistant from the foothills on either side, show that the minimum temperature occurs more than an hour later at the 150-foot level than at the base. This represents the length of time after sunrise required to overcome the inversion and bring the stratum of air below the 150-foot station approximately into adiabatic equilibrium.

A comparison between the temperature differences on the wireless tower and on the hillsides on either side of the valley at Medford indicates that during the night the hillside temperatures are somewhat lower than the temperature of the free air at the same levels, as would be expected. The differences, however, are slight.

TABLE 1.—*Minimum temperatures on clear nights during winter of 1917–18 at hill and vall ey stations near Pomona, Calif.*

[Station numbers and elevations (m. s. l.); see fig. 1.]

Date.	2 (1,230 feet).	1 (1,400 feet).	Departure.	9 (825 feet).	8 (950 feet).	Departure.	7 (1,075 feet).	Departure.
1918.								
Jan. 6	34.7	51.0	+16.3	30.0	38.6	+ 8.6	41.1	+11.1
10	35.0	40.0	+ 5.0	28.8	39.0	+10.2	39.2	+10.4
11	27.5	43.0	+15.5	25.0	32.7	+ 7.7	36.3	+11.3
12	28.4	42.5	+14.1	25.1	34.8	+ 9.7	36.2	+11.1
14	34.6	43.0	+ 8.4	31.8	39.0	+ 7.2	40.2	+ 8.4
17	36.5	53.0	+16.5	32.2	43.8	+11.6	44.8	+12.6
18	35.8	51.0	+15.2	32.9	43.2	+10.3	44.2	+11.3
20	33.4	41.7	+ 8.3	25.0	38.0	+13.0	37.1	+12.1
21	27.1	42.0	+14.9	23.8	35.0	+11.2	39.0	+15.2
22	25.8	40.8	+15.0	23.0	33.1	+10.1	34.1	+11.1
23	24.5	45.5	+21.0	23.1	39.0	+15.9	40.8	+17.7
24	34.6	52.0	+17.4	29.8	43.7	+13.9	47.4	+17.6
27	36.4	41.0	+ 4.6	31.0	37.0	+ 6.0	39.0	+ 8.0
28	28.5	43.0	+14.5	24.3	34.0	+ 9.7	36.0	+11.7
29	27.5	44.0	+16.5	24.8	33.0	+ 8.2	35.9	+11.1
30	36.3	40.7	+ 4.4	33.7	41.0	+ 7.3	41.0	+ 7.3
31	33.0	43.0	+10.0	32.1	40.0	+ 7.9	40.0	+ 7.9
1918.								
Feb. 1	27.8	42.0	+14.2	26.2	38.7	+12.5	38.8	+12.6
2	28.6	45.0	+16.4	26.0	35.[illegible]	+ 9.2	36.2	+10.2
3	31.3	49.0	+17.7	28.1	39.0	+10.9	41.0	+12.9
4	32.0	54.0	+22.0	26.8	43.0	+16.2	42.1	+15.3
5	33.7	51.0	+17.3	30.0	39.1	+ 9.1	43.0	+13.0
6	33.7	44.8	+11.1	30.6	38.1	+ 7.5	41.0	+10.4
8	34.0	46.0	+12.0	32.9	41.3	+ 8.4	42.9	+10.0
9	35.3	49.0	+13.7	26.8	41.6	+14.8	48.0	+21.2
10	34.0	55.5	+21.5	28.0	49.8	+21.8	49.9	+21.9
11	29.7	51.0	+21.3	24.5	36.9	+12.4	42.0	+17.5
14	37.0	44.0	+ 7.0	32.9	41.8	+ 8.9	42.2	+ 9.3
16	28.2	45.0	+16.8	27.0	42.0	+15.0	41.4	+14.4
Average	31.[illegible]	46.0	+14.1	28.1	39.0	+10.[illegible]	40.7	+12.6

TABLE 2.—*Minimum temperatures on clear nights on south slope of San Jose Hill, near Pomona, Calif.*

[Stations (elevation above base station).]

Date.	Base.	25 feet.		50 feet.		75 feet.		100 feet.		125 feet.		175 feet.		225 feet.		275 feet.	
1918.																	
Dec. 3	32.0	36.1	+4.1	46.6	+14.6	48.9	+16.9	47.0	+15.0	53.2	+21.2	55.0	+23.0	55.0	+23.0	51.5	+19.5
4	31.0	35.5	+4.5	40.9	+ 9.9	41.6	+10.6	47.1	+16.1	51.2	+20.2	57.6	+26.6	53.2	+22.2	52.2	+21.2
10	28.9	31.9	+3.0	36.1	+ 7.2	36.0	+ 7.1	37.5	+ 8.6	40.2	+11.3	41.0	+12.1	42.2	+13.3	40.0	+11.1
13	29.0	31.5	+2.5	36.9	+ 7.9	36.1	+ 7.1	36.2	+ 7.2	39.0	+10.0	39.0	+10.0	41.0	+12.0	39.5	+10.5
14	30.1	34.0	+3.9	43.5	+13.4	43.8	+13.7	43.0	+12.9	48.0	+17.9	48.5	+18.4	48.0	+17.9	48.0	+17.9
15	29.4	33.0	+3.6	43.7	+14.3	42.8	+13.4	44.5	+15.1	47.1	+17.7	47.6	+18.2	48.3	+18.9	46.0	+16.6
16	30.8	34.8	+4.0	40.0	+ 9.2	40.6	+ 9.8	40.9	+10.1	43.3	+12.5	43.8	+13.0	43.9	+13.1	42.0	+11.2
17	27.8	30.8	+3.0	36.8	+ 9.0	37.3	+ 9.5	38.3	+10.5	38.9	+11.1	40.4	+12.7	40.9	+13.1	41.0	+13.2
23	25.2	28.1	+2.9	32.1	+ 6.9	31.8	+ 6.6	33.2	+ 8.0	34.1	+ 8.9	34.1	+ 8.9	35.1	+ 9.9	33.5	+ 8.3
24	24.0	28.7	+4.7	36.0	+12.0	34.1	+10.1	35.2	+11.2	37.9	+13.9	38.7	+14.7	38.9	+14.9	37.9	+13.9
25	21.9	23.1	+1.2	30.2	+ 8.3	30.2	+ 8.3	31.1	+ 9.2	34.9	+13.0	35.8	+13.9	36.1	+14.2	35.3	+13.4
26	21.5	24.5	+3.0	36.1	+14.6	36.8	+15.3	36.8	+15.3	38.5	+17.0	40.2	+18.7	40.9	+19.4	39.1	+17.6
27	24.1	29.7	+5.6	37.3	+13.2	38.0	+13.9	40.8	+16.7	43.3	+19.2	45.1	+21.0	44.3	+20.2	42.1	+18.0
28	24.7	29.8	+5.1	44.0	+19.3	44.0	+19.3	45.8	+21.1	48.2	+25.5	49.9	+25.2	51.1	+26.4	45.9	+21.2
29	24.3	27.2	+2.9	35.8	+11.5	34.7	+10.4	35.3	+11.0	38.1	+13.8	38.1	+13.8	38.2	+13.9	38.1	+13.8
30	19.9	22.0	+2.1	26.9	+ 7.0	26.1	+ 6.2	28.1	+ 8.2	32.5	+12.6	33.1	+13.2	33.2	+13.3	30.9	+11.0
31	21.8	21.2	−0.6	27.8	+ 6.0	26.7	+ 4.9	29.5	+ 7.7	31.4	+ 9.6	31.3	+ 9.5	32.1	+10.3	30.2	+ 8.4
Jan. 1	19.8	21.0	+1.2	26.1	+ 6.3	25.1	+ 5.3	26.1	+ 6.3	28.0	+ 8.2	28.2	+ 8.4	29.1	+ 9.3	29.1	+ 9.3
2	19.9	21.3	+1.4	27.0	+ 7.1	27.0	+ 7.1	28.6	+ 8.7	31.0	+11.1	31.2	+11.3	31.7	+11.8	30.6	+10.7
3	21.0	24.0	+3.0	31.0	+10.0	32.1	+11.1	33.9	+12.9	35.5	+14.5	36.5	+15.5	39.8	+18.8	39.2	+18.2
4	25.1	30.5	+5.4	41.7	+16.6	42.0	+16.9	42.7	+17.6	48.0	+22.9	48.8	+23.7	49.1	+24.0	48.0	+22.9
5	26.0	33.0	+7.0	42.9	+16.9	42.5	+16.5	42.7	+16.7	48.0	+22.0	49.0	+23.0	50.1	+24.1	49.9	+23.9
6	21.1	25.0	+3.9	33.3	+12.2	36.9	+15.8	40.8	+19.7	45.0	+23.9	47.0	+25.9	49.1	+28.0	45.0	+23.9
7	22.2	25.6	+3.4	35.0	+12.8	37.3	+15.1	41.0	+18.8	43.9	+21.7	45.0	+22.8	47.0	+24.8	43.7	+21.5
8	22.0	27.5	+5.5	39.2	+17.2	40.0	+18.0	40.0	+18.0	46.5	+24.5	47.2	+25.2	48.1	+26.1	47.7	+25.7
12	27.7	31.0	+3.3	36.1	+ 8.4	36.8	+ 9.1	38.9	+11.2	40.0	+12.3	40.4	+12.7	41.1	+13.4	40.6	+12.9
13	24.9	28.4	+3.5	38.6	+13.7	40.0	+15.1	40.1	+15.2	46.4	+21.5	46.8	+21.9	46.9	+22.0	45.0	+20.1
14	21.2	25.1	+3.9	34.2	+13.0	34.8	+13.6	35.8	+14.6	41.0	+19.8	41.9	+20.7	42.0	+20.8	41.9	+20.7
15	21.5	27.2	+5.7	38.5	+17.0	39.0	+17.5	41.9	+20.4	44.0	+22.5	44.0	+22.5	45.9	+24.4	40.3	+18.8
18	28.5	32.1	+3.6	41.0	+12.5	41.6	+11.1	41.8	+13.3	44.6	+16.1	45.8	+17.3	47.0	+18.5	44.8	+16.3
22	31.9	35.1	+3.2	43.1	+11.2	42.8	+10.9	44.1	+12.2	46.9	+15.0	49.9	+18.0	49.3	+17.4	49.1	+17.2
23	29.8	34.1	+4.3	40.1	+10.3	41.0	+11.2	45.7	+15.9	49.5	+19.7	49.9	+20.1	50.3	+20.5	49.1	+19.3
24	28.1	32.0	+3.9	42.0	+13.9	41.0	+14.9	43.8	+15.7	46.7	+18.6	47.1	+19.0	48.4	+20.3	47.0	+18.9
26	25.3	29.0	+3.7	36.1	+10.8	35.2	+ 9.9	36.4	+11.1	37.3	+12.0	39.0	+13.7	41.0	+15.7	39.0	+13.7
27	26.0	31.0	+5.0	43.4	+17.4	42.2	+16.2	44.0	+18.0	45.2	+19.2	47.0	+21.0	50.0	+24.0	45.3	+19.3
28	24.2	32.9	+8.8	42.7	+18.6	42.0	+17.9	44.8	+20.7	47.8	+23.7	48.1	+24.0	49.0	+24.9	48.0	+23.9
Feb. 3	27.3	29.7	+2.4	34.3	+ 7.0	33.6	+ 6.3	34.9	+ 7.6	37.6	+10.3	37.0	+ 9.7	37.8	+10.5	34.7	+ 7.4
4	26.1	29.1	+3.0	34.3	+ 8.2	33.2	+ 7.1	34.0	+ 7.9	36.0	+ 9.9	36.5	+10.4	37.1	+11.0	36.8	+10.7
12	29.0	30.4	+1.4	34.4	+ 5.4	33.2	+ 4.2	35.3	+ 6.3	36.2	+ 7.2	37.0	+ 8.0	37.5	+ 8.5	36.9	+ 7.9
13	27.7	29.8	+2.1	35.8	+ 8.1	34.8	+ 7.1	36.7	+ 9.0	38.0	+10.3	38.3	+10.6	39.1	+11.4	37.1	+ 9.4
14	28.8	31.2	+2.9	37.4	+ 9.2	37.1	+ 8.9	38.5	+10.3	40.3	+12.1	40.8	+12.6	41.9	+13.7	39.3	+11.1
15	31.1	33.9	+2.8	38.8	+ 7.7	37.6	+ 6.5	38.0	+ 6.9	39.5	+ 8.4	40.2	+ 9.1	41.0	+ 9.9	40.9	+ 9.8
16	29.5	32.7	+3.2	43.1	+13.6	41.2	+11.7	42.1	+12.6	42.9	+13.4	42.8	+13.3	42.7	+13.2	42.6	+13.1
18	27.8	30.1	+2.3	33.1	+ 5.3	32.0	+ 4.2	33.4	+ 5.6	34.9	+ 7.1	35.3	+ 7.5	35.8	+ 8.0	34.2	+ 6.4
19	26.0	28.0	+2.0	35.0	+ 9.0	34.0	+ 8.0	36.0	+10.0	36.7	+10.7	37.1	+11.1	38.0	+12.0	36.7	+10.7
Average	25.9	29.4	+3.5	37.2	+11.3	37.2	+11.3	38.6	+12.7	41.4	+15.5	42.3	+16.4	42.8	+16.9	41.2	+15.3

TABLE 3.—*Medford, Oreg., minimum temperatures and temperature inversions on clear nights at stations shown in fig. 9.*

	Stations.							Base wireless.	150 feet.		300 feet.		6.	7.		8.	
	4.	3.		2.		1.											
Apr. 1	37.5	......	......	......	......	38.0	+0.5	33.9	39.1	+ 5.2	38.4	+ 4.5	33.6	33.3	−0.3	36.1	+ 2.5
2	25.9	......	......	......	......	28.4	+2.5	22.9	29.0	+ 6.1	29.8	+ 6.9	23.4	25.0	+1.6	27.3	+ 3.9
3	22.0	......	......	......	......	24.1	+2.1	19.2	25.8	+ 6.6	26.8	+ 7.6	19.7	21.2	+1.5	24.0	+ 4.3
4	24.1	......	......	......	......	27.7	+3.6	22.9	28.8	+ 5.9	33.8	+10.9	23.0	24.0	+1.0	28.0	+ 5.0
5	30.3	......	......	......	......	33.0	+2.7	28.9	33.0	+ 4.1	34.4	+ 5.5	28.9	30.7	+1.8	33.0	+ 4.1
6	37.8	......	......	......	......	38.0	+0.2	36.4	39.3	+ 2.9	40.3	+ 3.9	35.1	36.1	+1.0	38.7	+ 3.6
10	35.2	......	......	......	......	37.1	+1.9	32.8	33.0	+ 0.2	37.7	+ 4.9	31.8	32.7	+0.9	36.4	+ 4.6
11	39.0	......	......	......	......	39.1	+0.1	38.0	39.0	+ 1.0	42.1	+ 4.1	37.0	37.1	+0.1	38.5	+ 1.5
12	37.0	38.4	+1.4	......	......	38.1	+1.1	37.0	39.0	+ 2.0	39.4	+ 2.4	36.1	36.9	+0.8	38.0	+ 1.9
13	32.2	33.0	+0.8	......	......	32.4	+0.2	31.0	32.0	+ 1.0	33.0	+ 2.0	30.4	30.3	−0.1	30.3	− 0.1
15	30.1	31.0	+0.9	......	......	30.3	+0.2	27.0	30.1	+ 3.1	31.6	+ 4.6	27.3	28.1	+0.8	29.1	+ 1.8
18	32.8	37.0	+4.2	37.5	+4.7	37.0	+4.2	29.9	38.0	+ 8.1	38.2	+ 8.3	30.0	32.9	+2.9	37.2	+ 7.2
19	40.7	43.1	+2.4	44.0	+3.3	43.0	+2.3	35.5	44.9	+ 9.4	46.9	+11.4	33.0	35.9	+2.9	44.8	+11.8
20	37.4	44.1	+6.7	44.1	+6.7	43.2	+5.8	43.4	45.3	+ 1.9	46.7	+ 3.3	34.1	37.0	+2.9	44.0	+ 0.9
21	40.1	46.1	+6.0	47.0	+6.9	46.1	+6.0	36.6	46.1	+ 9.5	48.0	+11.4	36.8	40.1	+3.3	46.5	+ 9.7
22	35.1	39.0	+3.9	39.7	+4.6	39.0	+3.9	30.1	40.9	+10.8	42.1	+12.0	30.4	32.9	+2.5	39.2	+ 8.8
23	35.0	36.4	+1.4	37.0	+2.0	37.0	+2.0	31.8	39.1	+ 7.3	38.3	+ 6.5	30.3	32.2	+1.9	37.0	+ 6.7
26	30.1	34.2	+4.1	36.7	+6.6	37.0	+6.9	26.0	33.9	+ 7.9	38.7	+12.7	25.8	28.1	+2.3	34.0	+ 8.2
27	30.3	38.0	+7.7	38.1	+7.8	36.7	+6.4	27.0	36.9	+ 9.9	39.1	+12.1	25.9	29.1	+3.2	37.0	+11.1
28	32.1	39.9	+7.8	41.0	+8.9	40.3	+8.2	29.4	40.9	+11.5	42.8	+13.4	29.0	34.0	+5.0	39.8	+10.8
29	38.8	43.4	+4.6	44.0	+5.2	43.1	+4.3	35.0	45.2	+10.2	46.0	+11.0	34.8	36.7	+1.9	44.4	+ 9.6
30	35.5	39.8	+4.3	40.4	+4.9	41.6	+6.1	31.9	40.7	+ 8.8	43.4	+11.5	31.3	35.0	+3.7	39.0	+ 7.7
May 1	41.2	40.1	−1.1	42.0	+0.8	41.6	+0.4	33.9	40.3	+ 6.4	44.0	+10.1	32.7	35.9	+3.2	41.0	+ 8.3
2	45.1	49.0	+3.9	49.6	+4.5	50.8	+5.7	39.9	50.5	+10.6	53.1	+13.2	38.0	41.1	+3.1	48.0	+10.0
3	42.3	47.9	+5.6	49.9	+7.6	48.9	+6.6	38.3	48.2	+ 9.9	51.0	+12.7	36.8	39.7	+2.8	46.7	+ 9.9
4	38.2	41.9	+3.7	43.0	+4.8	43.3	+5.1	34.1	42.9	+ 8.8	43.0	+ 8.9	33.4	36.0	+2.6	40.5	+ 7.1
5	34.3	37.5	+3.2	39.0	+4.7	39.0	+4.7	30.6	39.2	+ 8.6	40.3	+ 9.7	29.4	32.0	+2.6	36.3	+ 6.9
6	33.1	35.1	+2.0	35.2	+2.1	35.0	+1.9	29.0	37.1	+ 8.1	39.4	+10.4	29.3	32.2	+2.9	36.8	+ 7.5
7	36.0	40.3	+4.3	41.0	+5.0	40.9	+4.9	32.3	41.2	+ 8.9	43.0	+10.7	31.7	34.0	+2.3	39.6	+ 7.9
11	34.4	37.0	+2.6	37.8	+3.4	38.0	+3.6	31.8	39.1	+ 7.3	40.1	+ 8.3	32.0	33.3	+1.3	38.0	+ 6.0
12	39.1	43.0	+3.9	43.3	+4.2	43.8	+4.7	35.6	43.6	+ 8.0	47.0	+11.4	34.8	37.1	+2.3	43.1	+ 8.3
13	40.0	44.0	+4.0	45.9	+5.9	45.6	+5.6	36.9	42.5	+ 5.6	48.7	+11.8	35.3	37.5	+2.2	44.0	+ 8.7
Average	35.1	38.1	+3.0	38.9	+3.8	38.7	+3.6	32.2	38.9	+ 6.7	40.8	+ 8.6	31.3	33.4	+2.1	38.0	+ 6.7

TABLE 4.—*Minimum temperatures and temperature inversions on clear nights at stations shown in fig. 15.*

Date.	Stations.						
	1. (1,520 feet.)	2. (1,720 feet.)		3. (1,555 feet.)		4. (1,490 feet.)	
Apr. 1	35.4	40.1	+4.7	39.9	+4.5	36.2	+0.8
7	31.0	32.2	+1.2	32.0	+1.0	30.8	−0.2
8	27.6	30.6	+3.0	30.2	+2.6	28.2	+0.6
11	27.9	30.0	+2.1	30.2	+2.3	28.1	+0.2
12	31.1	35.1	+4.0	35.1	+4.0	31.2	+0.1
14	26.8	29.1	+2.3	28.9	+2.1	28.0	+1.2
20	30.6	33.1	+2.5	33.6	+3.0	31.4	+0.8
22	33.0	37.1	+4.1	36.6	+3.6	33.1	+0.1
26	30.9	33.9	+3.0	34.6	+3.7	31.0	+0.1
28	37.9	43.0	+5.1	42.9	+5.0	37.1	−0.8
29	36.8	43.0	+6.2	41.2	+4.6	37.4	+0.6
30	41.0	47.4	+6.4	46.1	+5.1	41.0	−0.0
May 1	37.9	43.0	+5.1	43.9	+6.0	37.2	−0.7
3	32.7	37.0	+4.3	36.6	+3.9	32.0	−0.7
4	32.0	37.0	+5.0	36.2	+4.2	31.0	−1.0
5	31.0	36.2	+5.2	37.3	+6.3	30.0	−1.0
6	34.1	41.0	+6.9	39.8	+5.7	35.0	+0.9
7	36.5	42.9	+6.4	43.6	+7.1	36.8	+0.3
10	30.8	35.0	+4.2	34.7	+3.9	30.2	−0.6
Average	32.9	37.2	+4.3	37.0	+4.1	32.9	−0.0

TABLE 5.—*Minimum temperatures on clear nights on 15-foot tower in orange grove, near Pomona, Calif.*

Date.	Elevation above ground.		Departure.
	4.5 feet.	15 feet.	
1918.			
Jan. 23	23.8	25.2	+1.4
24	30.0	32.2	+2.2
28	26.1	26.1	0.0
29	25.2	26.0	+0.8
30	33.7	35.0	+1.3
31	33.7	34.8	+1.1
Feb. 1	27.9	28.7	+0.8
2	26.9	28.0	+1.1
3	28.7	30.0	+1.3
4	28.0	30.0	+2.0
5	31.0	33.2	+2.2
6	32.0	34.0	+2.0
10	28.2	31.9	+3.7
11	25.7	27.9	+2.2
12	39.0	40.1	+1.1
13	36.9	38.5	+1.6
14	33.6	35.0	+1.4
16	27.9	30.1	+2.2
17	26.8	29.0	+2.2
19	25.7	26.1	+0.4
Average	29.5	31.1	+1.6

TABLE 6.—*Minimum temperatures on clear nights on 15-foot tower in orange grove, near Pomona, Calif.*

Date.	Elevation above ground.								
	2 feet.	5 feet.		9 feet.		12 feet.		15 feet.	
1919.									
Jan. 12	29.0	29.8	+0.8	30.3	+1.3	30.0	+1.0	30.4	+1.4
13	26.2	27.0	+0.8	27.9	+1.7	28.0	+1.8	29.0	+2.8
14	22.2	22.8	+0.6	23.7	+1.5	23.9	+1.7	25.0	+2.8
15	24.2	25.1	+0.9	27.4	+3.2	28.0	+3.8	29.9	+5.7
18	29.8	30.1	+0.3	30.9	+1.1	31.1	+0.2	32.0	+2.2
22	32.5	33.5	+1.0	34.0	+1.5	34.1	+1.6	35.5	+3.0
23	31.1	32.3	+1.2	33.1	+2.0	34.9	+3.8	35.6	+4.5
24	28.5	29.3	+0.8	30.4	+1.9	30.7	+2.2	32.9	+4.4
1919.									
Jan. 26	26.3	27.0	+0.7	27.8	+1.5	27.8	+1.5	29.0	+2.7
27	26.9	28.0	+1.1	28.9	+2.0	29.0	+2.1	30.0	+3.1
28	25.2	27.0	+1.8	28.9	+3.7	29.4	+4.2	31.7	+6.5
Feb. 3	28.0	28.3	+0.3	29.0	+1.0	28.3	+0.3	29.7	+1.7
4	28.1	28.3	+0.2	29.7	+1.6	30.0	+1.9	31.0	+2.9
Average	27.5	28.3	+0.8	29.4	+1.9	29.6	+2.1	30.9	+3.4

TABLE 7.—*Minimum temperatures on clear nights on 40-foot tower in orange grove, Pomona, Calif.*

Date.	Elevation above ground.														
	5 feet.	10 feet.		15 feet.		20 feet.		25 feet.		30 feet.		35 feet.		40 feet.	
1919.															
Feb. 13	32.0	33.0	+1.0	34.0	+2.0	34.0	+2.0	35.0	+3.0	35.4	+3.4	35.8	+3.8	37.0	+5.0
14	32.4	33.4	+1.0	34.1	+1.7	34.7	+2.3	36.1	+3.7	37.9	+5.5	39.1	+6.7	41.0	+8.6
15	33.8	34.8	+1.0	35.2	+1.4	35.4	+1.6	36.3	+2.5	37.0	+3.2	37.0	+3.2	38.0	+4.2
16	36.0	36.9	+0.9	39.1	+3.1	39.4	+3.4	40.3	+4.3	41.2	+5.2	42.0	+6.0	44.7	+8.7
18	32.3	32.4	+0.1	33.0	+0.7	32.9	+0.6	34.0	+1.7	35.0	+2.7	35.0	+2.7	36.0	+3.7
19	31.3	31.3	0.0	32.4	+1.1	32.4	+1.1	33.8	+2.5	35.9	+4.6	36.8	+5.5	38.0	+6.7
21	29.0	29.0	0.0	31.0	+2.0	31.0	+2.0	32.0	+3.0	32.7	+3.7	33.0	+4.0	35.0	+6.0
24	30.1	30.3	+0.2	31.4	+1.3	31.4	+1.3	32.8	+2.7	33.4	+3.3	33.6	+3.5	34.5	+4.4
25	31.0	32.0	+1.0	33.0	+2.0	32.6	+1.6	33.3	+2.3	34.5	+3.5	35.7	+4.7	38.9	+7.9
26	32.0	32.1	+0.1	33.1	+1.1	33.6	+1.6	34.9	+2.9	35.7	+3.7	36.2	+4.2	37.2	+5.2
27	39.0	39.0	0.0	40.3	+1.3	40.5	+1.5	41.7	+2.7	41.9	+2.9	41.0	+2.0	41.8	+2.8
28	34.0	34.0	0.0	35.0	+1.0	35.0	+1.0	36.8	+2.8	37.4	+3.4	38.0	+4.0	39.8	+5.8
Nov. 28	26.8													29.1	+2.3
29	27.0													32.1	+5.1
30	28.6					31.9	+3.3							34.9	+6.3
Dec. 3	35.0					40.2	+5.2							42.3	+7.3
10	31.1					34.1	+3.0							37.2	+6.1
11	30.0					35.8	+5.8							39.6	+9.6
14	27.6					30.0	+2.4							36.0	+8.4
16	32.6					36.0	+3.4							44.0	+11.4
17	37.7					40.9	+3.2							46.0	+8.3
18	35.1					42.1	+7.0							45.2	+10.1
19	33.0					38.3	+5.3							45.3	+12.3
20	37.1	39.6	+2.5			42.5	+5.4							48.3	+11.2
21	38.0	40.1	+2.1	41.7	+3.7	42.4	+4.4	44.0	+6.0	45.7	+7.7	47.1	+9.1	49.3	+11.3
23	34.1	36.1	+2.0	38.0	+3.9	39.5	+5.4	42.0	+7.9	43.1	+9.0	45.0	+10.9	45.0	+10.9
24	41.0	43.2	+2.2	44.9	+3.9	46.0	+5.0	47.4	+6.4	49.0	+8.0	50.7	+9.7	52.1	+11.1
25	41.0	44.2	+3.2	45.1	+4.1	46.0	+5.0	47.0	+6.0	48.7	+7.7	50.0	+9.0	52.0	+11.0
26	38.7	40.2	+1.5	42.7	+4.0	44.0	+5.3	46.0	+7.3	48.0	+9.3	49.2	+10.5	51.6	+12.9
27	35.1	37.1	+2.0	39.0	+3.9	40.7	+5.6	43.0	+7.9	44.1	+9.0	45.0	+9.9	47.0	+11.9
28	41.4	43.6	+2.2	45.4	+4.0	47.0	+5.6	49.8	+8.4	51.0	+9.6	52.1	+10.7	54.9	+13.5
29	38.1	40.3	+2.2	42.0	+3.9	42.8	+4.7	44.0	+5.9	45.3	+7.2	47.0	+8.9	49.0	+10.9
30	32.0	35.1	+3.1	38.0	+6.0	40.0	+8.0	41.4	+9.4	43.0	+11.0	44.0	+12.0	45.0	+13.0
31	29.9	31.8	+1.9	34.0	+4.1	37.0	+7.1	39.0	+9.1	40.0	+10.1	40.3	+10.4	41.0	+11.1
1920.															
Jan. 6	30.0	31.0	+1.0	31.7	+1.7	32.0	+2.0	33.0	+3.0	33.9	+3.9	34.9	+1.9	35.7	+5.7
7	27.5	28.8	+1.3	29.1	+1.6	29.9	+2.4	30.5	+3.0	31.0	+3.5	31.7	+4.2	32.0	+7.2
8	26.0	28.0	+2.0	29.9	+3.9	31.7	+5.7	33.0	+7.0	34.0	+8.0	35.0	+9.0	35.1	+9.1
9	26.1	28.0	+1.9	29.6	+3.5	31.0	+4.9	32.9	+6.8	34.5	+8.4	35.1	+9.0	36.0	+9.9
10	30.2	32.0	+1.8	33.0	+2.8	34.0	+3.8	35.1	+4.9	36.6	+6.4	37.8	+7.6	38.9	+8.7
13	30.1	31.9	+1.8	32.8	+2.7	33.7	+3.6	35.0	+4.9	35.6	+5.5	36.4	+6.3	37.1	+7.0
14	32.0	34.0	+2.0	36.8	+4.8	37.6	+5.6	38.7	+6.7	39.6	+7.6	40.7	+8.7	42.0	+10.0
15	29.0	30.9	+1.9	33.0	+4.0	34.0	+5.0	36.0	+7.0	37.0	+8.0	37.0	+8.0	37.4	+8.4
18	39.0	41.0	+2.0	42.0	+3.0	44.0	+5.0	46.1	+7.1	49.6	+10.6	51.0	+12.0	54.0	+15.0
25	38.1	39.3	+1.2	40.1	+2.0	41.0	+2.9	42.6	+4.5	44.9	+6.8	46.0	+7.9	49.1	+11.0
29	34.7	36.0	+1.3	37.6	+2.9	39.6	+4.9	42.8	+8.1	45.0	+10.3	45.0	+10.3	45.1	+10.4
Feb. 5	39.1	40.9	+1.8	42.0	+2.9	42.6	+3.5	43.4	+4.3	44.0	+4.9	44.5	+5.4	46.0	+6.9
6	37.7	40.0	+2.3	42.0	+4.3	42.7	+5.0	43.9	+6.2	45.6	+7.9	46.0	+8.3	47.1	+9.4
7	41.1	42.7	+1.6	43.4	+2.3	44.1	+3.0	46.3	+5.2	48.0	+6.9	49.1	+8.0	50.2	+9.1
11	33.5	34.4	+0.9	35.6	+2.1	35.6	+2.1	36.0	+2.5	36.4	+2.9	36.8	+3.3	37.0	+3.5
14	31.1	32.2	+1.1	33.4	+2.3	33.6	+2.5	34.3	+3.2	35.0	+3.9	36.0	+4.9	36.9	+5.8
15	34.6	35.8	+1.2	37.2	+2.6	38.0	+3.4	38.9	+4.3	39.9	+5.3	40.7	+6.1	41.4	+6.8
Average	33.9	35.3	+1.4	36.7	+2.8	37.5	+3.6	39.0	+5.1	40.2	+6.3	41.0	+7.1	42.3	+8.4

TABLE 8.—*Minimum temperatures on clear nights on 35-foot tower in pear orchard, Medford, Oreg.*

Date.	Elevation above ground.						
	5 feet.	15 feet.		25 feet.		35 feet.	
1919.							
Apr. 11	27.3	28.2	+0.9	29.8	+2.5	29.0	+1.7
12	29.9	30.9	+1.0	31.1	+1.2	31.0	+1.1
14	25.1	26.2	+1.1	27.9	+2.8	28.0	+2.9
20	29.4	30.6	+1.2	32.0	+2.6	31.7	+2.3
22	30.9	31.9	+1.0	33.2	+2.3	33.9	+3.0
26	29.2	30.9	+1.7	31.1	+1.9	32.0	+2.8
28	34.4	36.7	+2.3	37.4	+3.0	38.1	+3.7
29	34.0	36.9	+2.9	38.0	+4.0	39.0	+5.0
30	38.0	40.1	+2.1	42.0	+4.0	42.9	+4.9
May 1	32.6	34.2	+1.6	36.2	+3.6	38.0	+5.4
3	29.9	32.5	+2.6	33.5	+3.6	34.3	+4.4
4	28.0	30.1	+2.1	31.8	+3.8	33.0	+5.0
5	26.8	29.3	+2.5	31.8	+5.0	33.6	+6.8
6	30.6	32.8	+2.2	34.6	+4.0	36.7	+6.1
7	31.0	33.0	+2.0	35.0	+4.0	37.0	+6.0
10	28.0	29.9	+1.9	31.0	+3.0	31.1	+3.1
1920.							
Apr. 11	30.0	31.3	+1.3	32.5	+2.5	32.7	+2.7
18	25.0	27.2	+2.2	29.0	+4.0	28.6	+3.6

Date.	Elevation above ground.						
	5 feet.	15 feet.		25 feet.		35 feet.	
1920.							
Apr. 22	27.6	29.0	+1.4	29.7	+2.1	29.7	+2.1
23	24.4	26.8	+2.4	27.8	+3.4	27.4	+3.0
24	26.5	28.6	+2.1	30.6	+4.1	30.3	+3.8
25	29.0	30.8	+1.8	32.7	+3.7	32.3	+3.3
26	32.2	34.9	+2.7	37.0	+4.8	37.8	+5.6
27	31.9	34.0	+2.1	37.2	+5.3	38.0	+6.1
28	32.1	34.1	+2.0	36.4	+4.3	37.0	+4.9
29	28.3	30.0	+1.7	33.0	+4.7	34.5	+6.2
May 2	29.0	30.0	+1.0	31.6	+2.6	32.3	+3.3
3	26.9	28.9	+2.0	31.0	+4.1	31.1	+4.2
4	27.0	29.0	+2.0	30.3	+3.3	31.0	+4.0
5	31.6	34.0	+2.4	35.9	+4.3	36.3	+4.7
6	32.7	35.1	+2.4	36.8	+4.1	37.2	+4.5
7	36.9	39.1	+2.2	42.1	+5.2	43.7	+6.8
8	37.1	39.7	+2.6	41.5	+4.4	42.6	+5.5
10	29.7	31.0	+1.3	32.6	+2.9	33.0	+3.3
11	31.0	32.6	+1.6	34.1	+3.1	34.9	+3.9
14	30.1	32.9	+2.8	34.5	+4.4	35.0	+4.9
Average	30.1	32.0	+1.9	33.7	+3.6	34.3	+4.2

EVAPORATION AND FOREST FIRES.

By E. N. MUNNS, Forest Examiner.

(California District U. S. Forest Service, Feb. 17, 1921.)

SYNOPSIS.

Hitherto, apparently, little attempt has been made by foresters and meteorologists to correlate the factors of climate and forest fires. The purpose of this paper is to show that the occurrence and spread of large forest fires are coincident with a greatly increased rate of evaporation or a decrease in vapor pressure.

Since evaporation is a climatic complex dependent on the three major factors of temperature, humidity, and wind, the influence of any one of these may be offset by a pronounced change in either or both of the other two.

The close relation between periods of high evaporation and forest fires is strikingly brought out in figures 1 and 2. These figures also show that the rate of evaporation does not follow constantly either temperature, humidity, or wind. In some cases it follows wind alone, in others temperature, while in still others it follows changes in relative humidity only.

In southern California the wind direction is highly important. For example, an east wind blowing directly off the great deserts, brings excessively dry, hot air, resulting in extraordinary dryness in a short time.

In examining the vapor pressure data for the period 1911–1920, it was found that in those years and months when the average vapor pressure remained high a very small number of fires occurred, while in those years and months with a relatively low average vapor pressure there were uniformly periods of extreme hazard, and many bad fires occurred.—*H. L.*

Up to the present time there has been very little attempt on the part of foresters[1] and meteorologists[2] generally to correlate the different factors of climate and forest fires. Many foresters[3] are now devoting considerable time to a study of fire, its behavior, and the fundamental principles underlying its severity, its rate of spread, and its climatic relationship.

The causes which lead to the occurrence and rapid spread of large fires are not definitely known, but it has long been suspected that they are intimately related to meteorological conditions. The field force recognizes this, and in speaking of a fire, usually makes some such statement as "conditions were right for the fire to spread rapidly," or "it was an easy matter to control the fire because conditions were just right." What these "conditions" were has been largely a matter of conjecture. It is the purpose of the present paper to show how the occurrence and the spread of large fires are coincident with a greatly increased rate of evaporation or decrease in the vapor pressure

In the present study the data here given for evaporation were obtained at Converse experiment station in the San Bernardino Mountains. This station was located in the Angeles National Forest at an elevation of 6,000 feet, about 100 miles from the ocean, and in the transition zone between chaparral and a stunted Jeffrey pine forest. Evaporation data were secured from standardized porous cup atmometers exposed to the sun and wind at a height of 15 inches above the surface of the ground, in a location where a minimum of influence would be exerted by surrounding objects. The data given for any 24 hours end at 5 p. m. The amount of evaporation is expressed in cubic centimeters.

Evaporation is a climatic complex dependent on the three major factors of temperature, humidity, and wind. The influence of any one of these factors may be offset by a suitable change in either or both of the other two. How great an influence each may exert we do not know, but for general purposes they may be considered as being of equal weight. The evaporation rate may change with fluctuations in any one of the factors, following temperature, wind, or humidity.

How closely forest fires follow periods of high evaporation is shown in figures 1 and 2, where the data on daily evaporation are plotted with the size and occurrence of fires on three southern California forests. It is

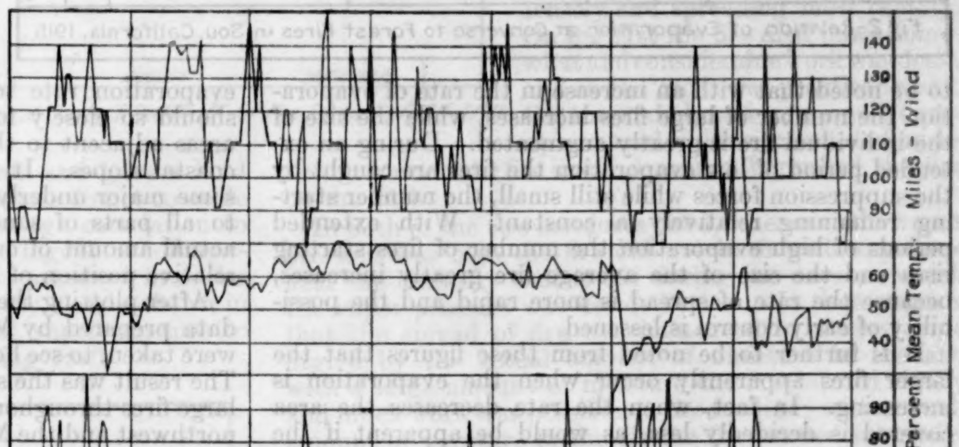

Fig. 1—Relation of Evaporation at Converse to Forest Fires in Sou. California. 1916

[1] Plummer, Fred Gordon: Lightning in relation to forest fires. U. S. Dept. Agr. Forest Service Bulletin 111, p. 39. 1912.

[2] Palmer, Andrew H.: Lightning and forest fires in California. U. S. Dept. Agr. MON. WEA. REV. March, 1917. 99–102.

[3] Show, S. B.: Climate and forest fires in northern California. Journal Forestry 17; No. 8, 965–980. December, 1919.

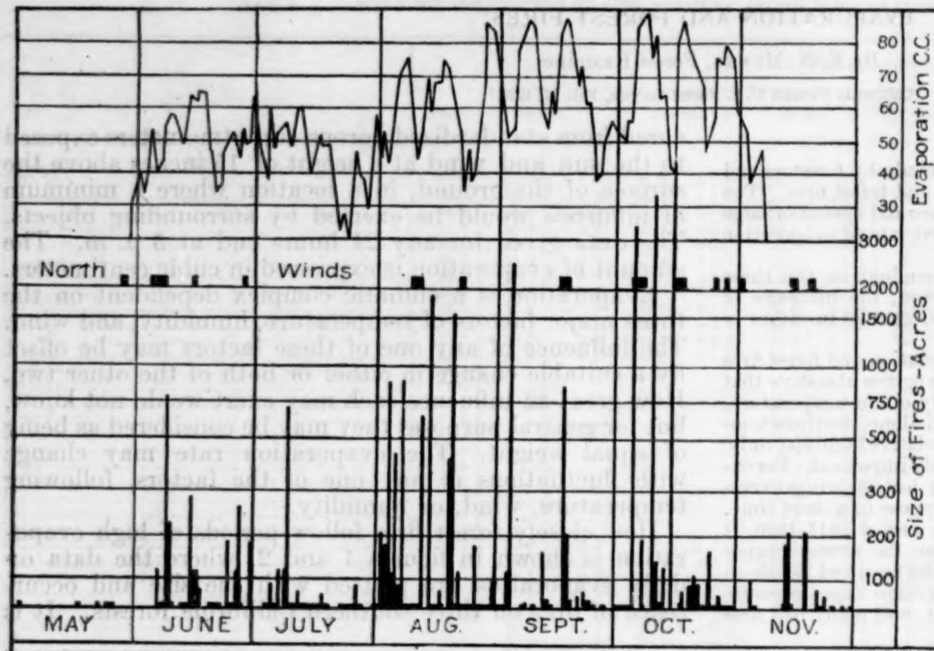

Fig 2-Relation of Evaporation at Converse to Forest Fires in Sou. California. 1915

to be noted that with an increase in the rate of evaporation the number of large fires increases, while the size of the individual fire is greatly augmented. During an extended period of low evaporation the fires are caught by the suppression forces while still small, the number starting remaining relatively a constant. With extended periods of high evaporation the number of fires starting rises and the size of the average fire greatly increases, because the rate of spread is more rapid and the possibility of early control is lessened.

It is further to be noted from these figures that the larger fires apparently occur when the evaporation is increasing. In fact, when the rate decreases the area covered is decidedly less, as would be apparent if the areas covered were plotted for the individual days during which the fire was spreading, rather than the total area plotted for the day on which the fire started, as was done here. The very largest fires, and those which have proved to be most difficult to control, have occurred during periods of high evaporation. The following examples from the Santa Barbara Forest illustrate this:

On August 19 there was a fire of 1,500 acres not controlled until the following night; the area burned was covered in two days but plotted on one. A fire of 2,500 acres is plotted on September 3 which was not controlled until the night of the fifth after burning three days. On October 4 is plotted a fire of 3,200 acres which was controlled after burning four days.

These figures also show that the rate of evaporation does not follow constantly either temperature, wind, or humidity. In some cases it follows wind alone, in others it follows temperature, while in still others it appears to follow relative humidity. Attention is also invited to the fact that the periods during which the north and east winds occurred were those in which the largest fires and those most difficult to control occurred. These north and east winds are essentially "desert" winds, and are caused by strong barometric differences. These winds coming from the great deserts are excessively dry, and no matter how wet the previous period has been rapid evaporation results and any fires occurring spread rapidly. In fact, in southern California it may be truly said that the fire season runs from January to December, as fires occur during periods of north winds throughout the entire winter season.

The writer has compiled and correlated the data on fire with wind direction for the period from 1913 to 1916, inclusive, for the three southern California national forests. In this connection it was noted that of 67 fires of over 500 acres, 50 occurred on days with north winds and but 20 on days with west winds. Of 42 fires of 1,000 acres or more, but three occurred with west, or ocean winds, while 39 occurred with north winds.

It has been shown that size and occurrence of fires follows the evaporation data very closely. This is a striking fact when it is considered that large parts of these three southern forests are influenced by marine conditions due to their proximity to the Pacific Ocean while other portions are under the direct influence of the Mohave Desert. It is also remarkable that an increase in the evaporation rate taken in this high mountain country should so closely follow the occurrence of fires both on areas adjacent to the desert and those fronting on the coastal slopes. It would therefore appear that there is some major underlying factor which applies equally well to all parts of southern California, and that while the actual amount of evaporation may not be the same, the relative position of high and low rates remains constant.

After plotting the data for southern California, the fire data prepared by Mr. S. B. Show for the Sierra Forests were taken, to see how far this general influence extended. The result was the same as for southern California. The large fires throughout the State, from the Klamath in the northwest and the Modoc in the lava region of the northeast, to the Sequoia in the south, occurred uniformly for two years during the same periods of high evaporation rate as in southern California, while the small fires were universally concentrated on the periods of low evaporation rate. In other words, as far as California was concerned, regional location had nothing to do with the spread of the fires when the evaporation changed from a low to a high rate, and all California comes under one major meteorological province. It is difficult to believe or understand that conditions can exist which make such a definite correlation possible between evaporation and the spread and occurrence of large fires, but the data admit of no other interpretation.

As our data on evaporation cover only the two years of 1915 and 1916, it was natural to turn to the Weather Bureau to determine whether any of the data they collect would permit of a correlation between evaporation and other meteorological factors. After considerable time spent in fruitless search it was found that the data on vapor pressure gave the desired result and that the reverse of the vapor pressure curve was essentially of the same form as the curve of evaporation. Unfortunately, it has not been possible to make a direct correlation in southern California between evaporation and vapor pressure, as Los Angeles, the only station at which these data are secured, has a climate influenced to a large extent by the proximity of the ocean. However, a comparison was made with data collected at Fresno and

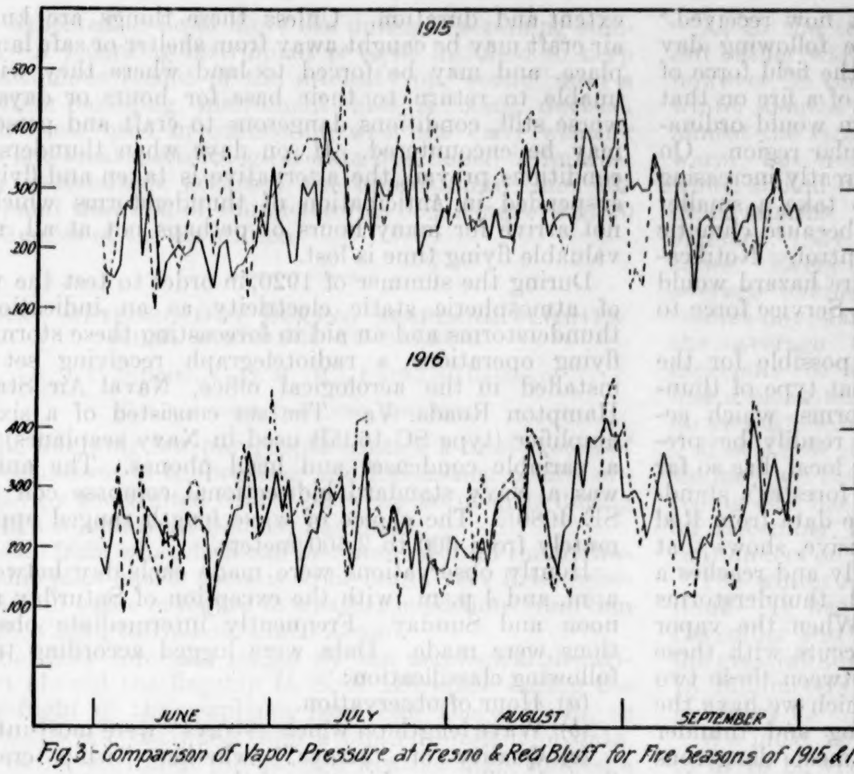

Fig. 3 - Comparison of Vapor Pressure at Fresno & Red Bluff for Fire Seasons of 1915 & 1916.

at Red Bluff, which are valley points and have a land type of climate (fig. 3). While the points do not coincide in every individual case, there is enough correlation to make certain that vapor pressure is a big factor influencing evaporation, and therefore the spread of fires, for which data are available. This is very clearly shown in figure 4, which gives the relation of vapor pressure to two large fires which occurred during 1920.

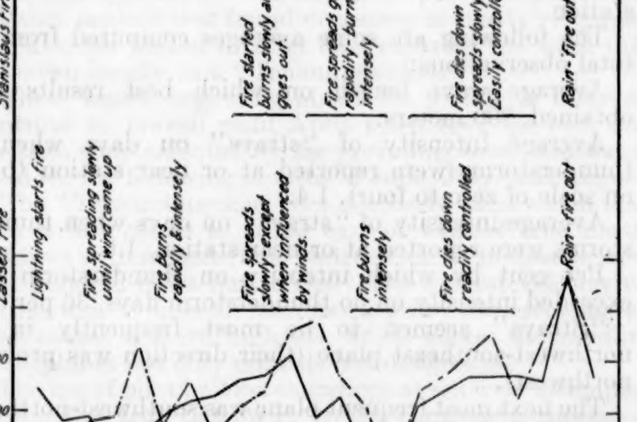

Fig. 4. Relation of Large August 1920 Fires to Vapor Pressure Conditions

On August 4 a lightning storm occurred on the Lassen Forest which was responsible for the setting of a large number of fires.[4] A few of these burned for several days unchecked. The men on the fire line engaged in fighting the fire noted that on some days the fire was difficult to control and burned intensely, while on other days it burned more slowly and could be closely approached. It is found that the days on which the fire spread very rapidly were those on which the vapor pressure was low, while those on which the fire spread but slowly and could be approached the vapor pressure was considerably higher, though the occurrence of wind upsets the absolute correlation.

On the Stanislaus Forest a fire started on August 12, in a narrow river canyon. For three days it was believed it would burn itself out with no damage, but on the fourth day the fire came up out of the canyon and spread rapidly in all directions. On the 18th the fire was burning most intensely and spreading most rapidly. On the 21st the fire died down somewhat and considerable work was done, and on the 22d it was practically out. On the 23d, however, a small flare-up occurred which necessitated additional work on the fire line. A rain extinguished the fire on the 24th.

In both of the two instances cited, whenever the vapor pressure was high the fire did not burn with anywhere near the intensity that it did during the days on which the vapor pressure was decidedly low. It thus appears that the spread of fire was influenced to a very large degree by the actual amount of moisture in the air; with a large amount of moisture the fire burned slowly and much work was possible on the fire line; with a small amount of moisture in the air the fire burned intensely, making it difficult to get within striking distance of the flames to do effective work at close quarters.

It is noteworthy that the occurrence of fires and the rate of evaporation do not follow the course of relative humidity. Relative humidity is such a changeable factor, varying with gusts of wind, temperature, etc., that it is usually unreliable except for the immediate period during which it is determined, though it does follow temperature in its general trend. The absolute humidity (indicated by the vapor pressure) is the weight of water vapor in a given space. While there is a variation from hour to hour and from day to day in this factor, the change is more gradual and more uniform than that of relative humidity. These fluctuations in actual moisture content of the atmosphere are brought about in varying degrees during the day by evaporation from both land and water surfaces, by transpiration by plant life, and by condensation in the form of rain, dew, or frost. These changes are continuously operating in some manner, evaporation being much more active during the warmer part of the day than during the night, when temperatures are low and the dew point is reached or approximated.

For the control of forest fires it appears that some form of prediction of extreme changes in vapor pressure is needed, and this the Weather Bureau believes it may

[4] See Palmer, A. H.: Lightning and forest fires, Mo. WEATHER REV., August, 1920, 48: 452-453.

be possible to supply, augmenting that now received.[5] If it were known in advance that the following day would have a very low vapor pressure, the field force of the Forest Service, upon the occurrence of a fire on that day, could dispatch more men to it than would ordinarily be required for a fire in that particular region. On the other hand, with a knowledge of a greatly increasing vapor pressure it would be possible to take a smaller number of men than in the first case, because climatic conditions would be in favor of easy control. Notification in advance of periods of extreme fire hazard would make it possible to augment the Forest Service force to care for the emergency.

Up to the present it has not been possible for the Weather Bureau to predict the local heat type of thunderstorms. The widespread thunderstorms, which accompany low-pressure areas, can very readily be predicted, but the heat type, being entirely local, has so far not been as carefully studied from the forester's standpoint as we should like. A study of the data from Red Bluff for the period 1911 to 1920, inclusive, shows that when the vapor pressure increases rapidly and reaches a point of about 0.380 inch (Hg.) local thunderstorms occur in the high mountain region. When the vapor pressure rises above 0.420 inch rain occurs with these convectional storms. The difference between these two extremes is the danger period during which we have the "dry lightning" storms, when lightning and thunder occur without rain. These are the most dangerous periods for the forest; during such times a large number of fires start, and as no rain falls they have a chance to spread to large size before they can be reached by the field force.

In going over the vapor-pressure data for the period from 1911 to 1920 it was found that in those years and months when the average monthly vapor pressure remained high a very small number of fires occurred, while in those years and months with a relatively low average monthly vapor pressure there were uniformly periods of extreme hazard and many bad fires occurred. Should it be possible by some system of forecasting, such as that of the Scripps Institute [from ocean temperatures][6] or by the occurrence of sun spots, to determine in advance what a particular month would be like in the way of fire hazard, our protection system could be put on a much more stable and safer basis than at present.

The whole field of the relation of vapor pressure and evaporation to forest fires offers possibilities which certainly have not been considered to any great degree before. It is planned to study evaporation during the present season on the national forests throughout the State, in order that we may determine the danger points and the possibility of their prediction. If such a study could be made nation-wide, a long step forward would be taken in our knowledge of the physical controls of fire.

FORECASTING THUNDERSTORMS BY MEANS OF STATIC ELECTRICITY.

By FRANCIS W. REICHELDERFER.

[Naval Air Station, Hampton Roads, Va., Apr. 27, 1921.]

The thunderstorm is one of the greatest obstacles to routine flying during the summer months. At an aviation station it is important, therefore, to know the approximate time of arrival of thunderstorms, their extent and duration. Unless these things are known, air craft may be caught away from shelter or safe landing place, and may be forced to land where they will be unable to return to their base for hours or days; or, worse still, conditions dangerous to craft and personnel may be encountered. If, on days when thunderstorm conditions prevail, the alternative is taken and flying is suspended in anticipation of thunderstorms which do not arrive for many hours or perhaps not at all, much valuable flying time is lost.

During the summer of 1920, in order to test the value of atmospheric static electricity as an indication of thunderstorms and an aid in forecasting these storms for flying operations, a radiotelegraph receiving set was installed in the aerological office, Naval Air Station, Hampton Roads, Va. The set consisted of a six-step amplifier (type SC 1605B used in Navy seaplanes) with a variable condenser and head phones. The antenna was a Navy standard bidirectional compass coil (type SE 4080). The choice of wave length ranged approximately from 600 to 2,500 meters.

Hourly observations were made each day between 8 a. m. and 4 p. m., with the exception of Saturday afternoon and Sunday. Frequently intermediate observations were made. Data were logged according to the following classification:

(*a*) Hour of observation.

(*b*) Wave length on which "strays" were most intense.

(*c*) Quality of "strays," whether "whip cracks," "grinders," or combination of these.

(*d*) Intensity of "strays" whether faint, moderate, strong, or deafening.

(*e*) Number of "strays," i. e., whether continuous or intermittent. If intermittent, give number per minute.

(*f*) Directional plane to eight points in which "strays" were strongest, i. e., whether they appeared to lie in the north-south plane, the east-west plane, the northwest-southeast plane, or the northeast-southwest plane.

(*g*) Change in intensity since last observation, whether increasing or decreasing.

(*h*) Amount, azimuth, and size (small, medium, or towering) of any cumulo-nimbus clouds within sight of station.

The following are some averages computed from the total observations:

Average wave length on which best results were obtained, 900 meters.

Average intensity of "strays" on days when no thunderstorms were reported at or near station (based on scale of zero to four), 1.4.

Average intensity of "strays" on days when thunderstorms were reported at or near station, 1.9.

Per cent by which intensity on thunderstorm days exceeded intensity on no thunderstorm days, 36 per cent.

"Strays" seemed to lie most frequently in the northwest-southeast plane (their direction was probably northwest).

The next most frequent plane was southwest-northeast.

From the experience of last summer it is believed that the "static" recorder is a valuable instrument for aerological stations. The above averages minimize rather than magnify the actual usefulness of a "static" indicator in forecasting for aviation. It must be remembered that this attempt was the first of its kind at this station, and that the apparatus used was designed for radiotelegraphy, not for detection of "static" for meteorological purposes. Since under these conditions the "static" log was found of considerable value in forecasting thunderstorms in the vicinity of the air station,

[5] Beals, Edward Alden: The value of weather forecasts in the problem of protecting forests from fire. MO. WEATHER REV., February, 1914, 42: 111-119.

[6] See next REVIEW.

it is expected to be of more use during the coming summer. A recording instrument is to be installed to keep a continuous record of the intensity of "static" and a direction-recording instrument also is being devised. With these used in connection with the daily weather map and local meteorological data it is hoped to forecast with considerable accuracy the approximate time, extent, and duration of thunderstorms occurring within 20 or 30 miles of the air station.

NAVAL METEOROLOGY DURING SEAPLANE FLIGHTS FROM SAN DIEGO TO BALBOA.

By J. C. O'BRIEN, C. Q. M. (M.), United States Navy.

[U. S. S. *Aroostook*, Pacific Fleet, April, 1921.]

The following few paragraphs contain a brief sketch of the conditions of the weather and forecasting results obtained by the United States Navy meteorologists during the trip to and from Balboa, Panama.

Aside from what data can be obtained from the hydrographic pilot charts there is to be found very little information of value in regard to weather conditions from San Diego, Calif., to Balboa, Canal Zone.

The daily forecasts issued by the aerological department aboard the flagship U. S. S. *Aroostook* during the long flight of the seaplanes from San Diego, Calif., to Balboa, while compiled from a limited amount of data, and entirely without the use of a weather map, showed a remarkable percentage of correct conditions encountered during the trip both to and from Balboa, Panama.

The most valuable means of forecasting were obtained by the use of the barometer, thermometer, and hydrograph, together with a continual study of the clouds and appearance of the sky. A nephoscope was used to advantage in the cloud study.

The two most treacherous places for which to forecast along the coast were the Gulfs of Fonseca and Tehauntepec. It is in the latter of these that unusually strong winds prevail for days at a time, almost without apparent cause, and a barometer gives no indication of the intensity of these wind streams. In lieu of the practically infallible weather maps it was found necessary to partly rely upon old Mexican Indian weather lore, covering the wind that is known locally as a "Tehauntepecker."

These winds, beginning about the middle of October, continue to prevail until April when they die out, and are then supplemented by the prevailing south-southwest wind for the following months of June, July, and August.

The "Tehauntepecker" is a northerly wind which may vary a few points to either east or west of true north. It blows with considerable violence and is noticeable several hundred miles out to sea. The highest velocity recorded was 48 miles an hour as shown by the anemometer. This causes a short, high sea, which makes the handling of seaplanes not only difficult but dangerous.

The use of pilot balloon soundings at sea were attempted during this trip, but owing to the continuous motion of the ship and the heavy smoke from its stacks it was impossible to obtain any satisfactory results in this way.

WEATHER AT GENEVA DURING THE WINTER 1920-21.

[Reprinted from the *Journal de Geneve*, Mar. 29, 1921.]

(Translated by Lewis W. Haskell, American consul, Geneva, Switzerland, Mar. 29, 1921.)

The most characteristic feature of the winter 1920–21 is unquestionably its *dryness*.

As to the temperature, the winter has been normal but rather warm. It was not as normal, nor so warm, however, as the preceding winter. Last year, the three winter months of December, January, and February had almost the same temperature. This year, they were all warm, but unequally so; and the month of January, which should be the coldest, was much warmer than the other months. It may even be said that it was, after January, 1834, the warmest month of January in our series. Every day of the month has been in excess of the average temperature and none was under 0° C.. The coldest day, January 7, with 0.01°, was still 0.33° above the average temperature. This is extremely rare, especially in winter. The month of January, 1834, had a mean temperature of 5.14°; the year 1834 was in fact a quite exceptional year, with 11.48°.

If we now consider the precipitation of the winter, we may see that the winter 1920-21, as well as the preceding one, has been almost without snow; 4 centimeters on December 16, 3 centimeters on January 17, and 4 centimeters on February 2; 11 centimeters in all.

The winter season has been dry, but less so than we think. It has even rained rather often, especially in December and in January; but never in large amounts; the greatest amounts were 13 millimeters on December 3; 18 millimeters on January 13, and 9 millimeters on February 2.

We must not forget that if the actual winter seems to us to be very dry, it is because we compare it with the immediately preceding winters. During the last 25 years the winters have been characterized by much greater precipitation than for the 70 years preceding these 25 years:

Period from 1826 to 1895, 138 millimeters per winter.
Period from 1896 to 1920, 186 millimeters per winter.

There has then been a mean augmentation of almost 50 millimeters, which is very great, and this fact explains our opinion that a winter season with only 87 millimeters is a very dry winter after the very wet winters which have so long prevailed.

But the most characteristic feature of this last winter is that the dryness began in the autumn—September, 1920, with 182 millimeters; but October, with 65 millimeters, and especially November, with 12 millimeters, were under normal. This explains the actual dryness, because from September to February, there should have fallen, according to the average quantity for 95 years, 327 millimeters of rain, and the quantity has been only 164 millimeters—that is to say, exactly half of the ordinary quantity.

There have been, in the past, periods of these same five months which were also dry. We give them here below, the last years being given first:

Winter.	Amount of rain (in millimeters). October, November, and December.	February and March.	Total.	Temperature of the winter.
1920-21	77	87	164	Warm.
1908-9	61	89	150	Cold.
1904-5	51	88	139	Normal (cool).
1897-98	15	121	136	Rather warm.
1890-91	125	44	169	Very cold.
1879-80	108	87	195	Do.
1873-74	149	37	186	Normal.
1869-70	97	101	198	Rather cool.
1867-68	97	61	158	Normal.
1863-64	78	56	134	Cold.
1853-54	123	42	165	Do.

So one can see that there have been winters which were as dry as the last one. These dry winters were for the greatest part cold rather than warm; on the contrary, the last one was warm.

Level of the Lake Geneva.—This level is exceptionally low at the present time. We only find such low waters at the end of the winter of 1840, in March and in April. The level was at that time the same as it was on March 15 to 18 of this year.

Duration of the absolute dryness.—As we have seen, there had fallen 14 millimeters of rain on February 1 and 2, 1921. After that, we have had 41 days of absolute dryness, that is to say, until March 17, 1921. This is not the longest period of drought we have had; during the winter of 1896 we had a period of 41 days without rain.

ANOTHER NOTE IN REGARD TO THE PRIMARY CAUSE OF COLDS.

A former note [1] on this subject by John R. Weeks declares, that the conclusions [2] arrived at by C. M. Richter at the end of his paper on "Colds and their relation to the physics of the atmosphere," do not seem to be in accord with the most recent medical thought. Conclusion No. 1 in question reads: "Acute coryza, commonly called a 'cold,' depends for its development primarily on an excess of moisture in the air we inhale." The most recent medical thought, as expressed for instance in a 1920 edition of a standard textbook [3] refers to the primary cause of acute rhinitis (common colds) as follows: "Its most conspicuous cause is exposure to drafts of air and to the influence of the atmospheric vicissitudes that are especially prevalent during the winter and spring seasons." As we know, winter and spring are likewise the seasons for cyclonic weather. The textbook adds: "Hence local disturbances of the circulation due to exposure are to be regarded as the accidental means of preparing the soil for bacterial invasion." One of the conclusions (No. 6) in question states this same fact. The question of a bacillus rhinitis (Tunnicliff) may be considered as remaining in the experimental stage, although recent investigations disprove the pathogenic quality of the Tunnicliff bacillus for acute rhinitis (Hall [4]) and also discredit a filtrable virus as the cause of either common colds or influenza (Branham and Hall [4]).

In Mr. Weeks's note it is stated, that the expired air being "normally near the saturation point"—that "therefore saturated air per se can not cause a discharge from the mucous membranes." This process is much more complicated than these words would indicate and I may refer here to the following words of Dr. L. Hill [5]: "The air, which is breathed into the lungs, whatever be its content of moisture or temperature, is breathed out approximately at body temperature and saturated with moisture at this temperature. Cold saturated air is excessively dry when warmed up to body temperature and takes up much moisture from the body, warm saturated air (or even half saturated) far less. The breathing of cool air entails, then, much greater evaporation from respiratory membrane and consequent greater flow of lymph through and secretion of fluid from it. The membrane is better washed and kept clean from infecting microbes by such outflow." This latter assumption is contradicted by an eminent physician, the late Abraham Jacobi,[6] who states: "As long as the mucous membranes are in their normal condition the germs can not enter the tissues and the circulation. A catarrh removes this protection; the epithelia are swept away by the fluid. That is the chance for the living enemies."

If we consider, that about every five seconds 500 cc., more or less, of incoming air is trying to replace a similar amount of expired air inside the nasal cavities and the lungs, it seems clear, that such air must be subject to considerable mixing.

A change of vapor pressure of this mixed air must tax the vasomotor apparatus of the mucosa constantly. The export of moisture (Rubner [7]) at a mean temperature and humidity of the room air by the lungs of an adult per hour amounts to 17 gm. when resting, 19 gm. when deep breathing, 34 gm. when singing. Rubner found the evaporation value of the lungs at 77° F. and 6 per cent relative humidity to be 18.4 and at 81 per cent relative humidity to be 10.9 gm. It seems, that we are not materially affected even by a large export of moisture from our lungs, as long as the air is rather dry. It is a different matter when the incoming air contains such a surplus of aqueous vapor, that evaporation by the lungs becomes rather impossible (Hann [8]). Such a condition would seem to call for special aid by the vasomotor nervous system, which acts as a reflex apparatus. "The automatic work of this system, by dilating or contracting vessels under its control, regulates the outflow of heat, of serum, of mucus into the nasal cavities. Generally the moisture inside the nose appears to be insensible, similar to the perspiration insensibilis of the epidermis, but any unusual increase of moisture, brought by the inhaled air, may increase the swelling of the hygroscopic swell bodies of the mucosa to such an extent, that the reflex apparatus by dilating the blood vessels may cause an overflow of the reservoir" (Richter.[9]).

It is to be hoped that some experimental work may overcome the difficulty of determining the vasomotor work of the nasal mucosa under the varying vapor pressure conditions of the incoming and outgoing air. Until then we have to accept the fact that the nasal mucosa, as a hygroscopic substance, will share the hygroscopic nature of other organic substances, like wood for instance. The human vasomotor apparatus of the nose of course varies in its sensitiveness. When unusually sensitive to changes in its area, it may try at once to get rid of an excess of moisture by sneezing, or simply by dilating its blood vessels. Such a vasomotor rhinitis is well known. Acute coryza will depend to a great extent on the sensitiveness of the vasomotor system. Experience teaches that it develops principally at the beginning of or during the passage of a cyclonic weather condition and that it seems to be therefore primarily due to the effect of an excess of moisture in the air.

Any weather condition that is associated with an increase of the aqueous vapor content of the air—and this is typical of the cyclonic weather condition—will necessarily increase the water content of the hygroscopic nasal mucosa and will induce an increased secretion from it. This effect will be minimal and rather insensible in general, but it will favor a more or less increased "running of the nose" in proportion to the degree of sensitiveness of the individual vasomotor apparatus. The functioning of this apparatus, however, depends besides on many factors that influence the general condition of an individual.—*C. M. Richter.*

[1] Weeks, John R.: Note in regard to the primary cause of colds. Mo. WEATHER REV., December, 1920, 48: 690.
[2] Conclusions republished in Mo. WEATHER REV., September, 1920, 48: 507.
[3] Anders, J. M.: Textbook of the practice of medicine, 14th Ed., 1920.
[4] *Journal of Infectious Diseases*, Chicago, February, 1921, 28: No. 2.
[5] Hill, Leonard: Atmospheric environment and health. Mo. WEATHER REV., December, 1920, 48: 687-690.

[6] Jacobi, A.: Colds. *N. Y. Medical Journal*, Mar. 16, 1912.
[7] Rubner: Lehrbuch der Hygiene, 1907.
[8] von Hann, J.: Klimatologie, 1908.
[9] Richter, C. M.: Colds and their relation to the physics of the atmosphere. *Medical Record*, Dec. 6, 1913.

A BRIEF REPLY.

In his note to which Dr. Richter refers, the writer was restricted by the editor to only a few lines. It was, of course, impracticable to enter into a discussion and only a few words need be said now.

1st. I am glad to see that Dr. Richter accepts the bacterial nature of colds in general.

2d. I do not find in his quotation from Anders any statement that a *common* cold "depends for its development primarily on an excess of moisture in the air we breathe;" and I have nowhere seen concrete evidence that common colds are associated with "cyclonic weather."

3d. It is admitted that *some* persons are subject to harm from drafts; *some* persons have hay fever and rose colds; *some* persons have acute rhinitis because of occupational association with chemicals; and so on. But where do *most* people get their colds? The most recent and perhaps best authority that I have seen is the Hand Book of Therapy, 6th edition, October, 1920, published by the American Medical Association. On page 224 it says:

"Acute colds are always due to germs of some kind. A too dry atmosphere, which is the condition in so many houses to-day, may so irritate or congest the nostrils as to allow the least irritant to cause at first a simple inflammation of the mucous membrane, which congested area may later pick up and harbor, or cease to kill, germs. Outdoor air does not predispose to colds as much as indoor air, and persons whose occupation is indoors are more liable to have colds than those whose occupation is outdoors. * * * It is quite probable that chilling of the surface of the body congests the inner organs and possibly the mucous membrane of the air passages. If the mucous membrane of the nose is congested, it more readily becomes inflamed. * * * Some persons can not be exposed to a single draft on any part of the body without an acute coryza starting. * * * Other persons who do not have this susceptibility may become chilled, may be subjected to violent, cold, damp winds, and may even get wet and still never develop a nasal inflammation."

For recent experimental work see *Jour. A. M. A.;* **75:** 1500 E and note on another page of this magazine.—*John R. Weeks.*

NOTE ON SOME EFFECTS OF WEATHER CHANGES ON DISEASE.

The conditions of the vasomotor nerves of the skin and of the blood supply to the capillaries of the skin have much to do with the amount of blood that reaches other organs and surfaces of the body and thus with disease "feelings" and bacterial activity. Experiments on animals have recently demonstrated (**1**) that chilling of the body surface causes an anaemia of the mucous membranes of the nose and throat instead of a hyperemia as formerly supposed (**2**). Further, there is recent evidence (**3**) that "nerve impulses along vasomotor fibers may play upon the caliber not only of the arterioles but also of the capillaries and venules." Again, for example (**4**), if the splanchic nerves on the two sides are cut the intestinal region becomes congested and the effect in this case is so great that the general arterial pressure falls to a very low point.

The cause of "weather pains" in persons with arthritis, "rheumatism," fractures, amputated limbs, etc., has been a mystery. Dr. Pemberton, of the Presbyterian Hospital, Philadelphia, has thrown new light on the subject by the study of 400 cases of chronic arthritis under treatment in the Army (**5**). Arthritis is usually due to focal infection and is popularly called "rheumatism." Dr. Pemberton states that the blood supply of the joints, per se, in health as well as disease, is definitely poor and quotes the researches of Nichols and Richardson (**6**) also to that effect. It follows that further diminution of the blood supply to these parts by the action of weather conditions will cause an increase of rheumatic sensations and of bacterial activity in localities that are depleted, such as joints, fractures, amputations, and the mucous membranes of nose and throat. Respiratory functions of the blood are also a factor (oxygen content, etc.), and Dr. Pemberton says:

It has long been known that chronic sufferers from this disease (arthritis) undergo exacerbations that seem to be sharply related to disturbances of the weather. This is so definitely true that certain types of climate are recognizedly detrimental and others equally advantageous in their influence on this disease. If disturbance in the respiratory functions of the blood is a factor in the disease, it is almost axiomatic that wide fluctuations of the barometer and humidity would affect these cases, since the percentage saturation of hemoglobin by oxygen is a function of the partial pressure of oxygen in the alveolar air.

Following another line of investigation, E. G. Martin, of Stanford University (**7**), has found that the most obvious of the external factors that influence the daily work of factory employees are climatic, confirming in this respect the previous work of Ellsworth Huntington, of Yale University. It appears (to quote the review in the Journal of the American Medical Association) that certain days are more favorable to high output than others, and the influences that underlie the differences are such as to affect all workers in a single environment. Martin's data, as well as Huntington's and the studies of the New York Ventilation Commission, suggest that the temperature at which work is carried on is important. He shows that there is evidence that persistent exposure to temperature above 30 C. (86° F.) is unfavorable to strength. Relative humidities between 70 and 80 per cent appear to favor high strength showing.—*John R. Weeks.*

References.

(**1**) Jour. A. M. A.: *75*, p. 1500 E.

(**2**) Mo. Wea. Review, *48*, 9; pp. 507, 508.

(**3**) Jour. A. M. A.; *75*, 26 (Dec. 25, 1920), p. 1784.

(**4**) **Howell**, Physiology, 7th ed., 1918, p. 613.

(**5**) Jour. A. M. A.; *75*, 26 (Dec. 25, 1920), pp. 1761–1765.

(**6**) **Nichols, E. H.**, and **Richardson, F. L.**, Jour. A. M. A., *21*, 149, September, 1909.

(**7**) **Martin, E. G.**, Strength Tests in Industry, Pub. Health Rep., *35*, 1895 (Aug. 13, 1920).

WEATHER AND DISEASE.

The article by Dr. Leonard Hill on "Atmospheric Environment and Health" that appeared in the Monthly Weather Review for December, 1920, is, in the main, of high standard, but I think that exception can be taken to the first sentence. It is an old thought that things wild are free from contagious disease and disease epidemics, just as it is an old thought that night air, and even air in general, is a carrier of contagion. The American Indian and the Esquimaux were subject to consumption before the arrival of civilization as well as now. Wild animals and wild plants now have contagious diseases and doubtless always did have them. Bacteria of types now common are found in the oldest manuscripts, thousands of years old, embedded in the papyrus and clay, and in rocks of prehistoric times. Doubtless the cave dwellers of the glacial period were afflicted and the plants and animals. Bacteria are found deeply imbedded in the ice of newly exposed arctic regions.

Dr. Erwin Smith, director of the Laboratory of Plant Pathology, United States Department of Agriculture, believes that all plant families will ultimately be found to have characteristic bacterial diseases, though we now know only some of those that are most common.

I believe that weather and climate had and still do have much to do with the prevalence and character of contagious diseases, in spite of the added mass effect of increased population and crowding, but our knowledge needs enlargement and consolidation.—*John R. Weeks.*

DISINFECTING ACTION OF SUN'S RAYS ON TUBERCLE BACILLI.

[Reprinted from *Schweizerischer medizinische Wochenschrift*, Basel, Dec. 2, 1920, 50: No. 49. Reviewed in *Journal A. M. A.*, Jan. 29, 1921, 76: No. 5.]

Bergen reports as the results of his extensive tests at Leysin that direct exposure of virulent tubercle bacilli to the sunlight, at an altitude of 1,360 meters, rendered them innocuous when injected into the peritoneum of guinea pigs after an exposure of half an hour during the summer. An hour's exposure was required for this during the spring and fall, and a little longer during the winter. His research has further convinced him, he says, that the share of ultraviolet rays in this action of the sunlight has been much overestimated.

INFLUENCE OF TEMPERATURE ON THE NUMBER OF DEATHS FROM INFANTILE DIARRHEA AT PARIS.

By LOUIS BESSON.

[Abstracted from *Comptes Rendus*, Paris Acad., Feb. 14, 1921, pp. 401–404.]

It is well known that infantile diarrhea is increasingly fatal with rise of temperature in summer. This paper gives a quantitative determination of that relation, based upon the data given in the *Bulletin hebdomadaire de Statistique municipale* of Paris. The meteorological data are those recorded by the Montsouris observatory. It was found that the effect of temperature begins to show with a mean temperature of 16.5° C. Below that temperature there is no apparent relation, but above, the number of deaths increases rapidly. Eliminating the deaths which would occur without the influence of temperature, the author gives the effect of mean temperatures 1°, 3°, 5°, 7°, and 9° above 16.5° and finds the number of deaths per hundred corresponding to be 5, 11, 20, 41, and 62, respectively. He deduces mathematical expressions by means of which the number of deaths can be calculated, and the figures calculated corresponding to those just given are 3, 10, 21, 38, and 63, respectively. Expressions are given for the calculation of the number of deaths for any week. Grouping by years, the number of deaths for a 10-year period were calculated with an error of about 1 per cent. Other meteorological elements were tried with a view to discovering other relations, but the results were negative, indicating that temperature is the only element having a direct effect on mortality from this disease.—*C. L. M.*

EXCHANGE OF WIRELESS WEATHER REPORTS BY VESSELS.

The Weather Bureau recently received from Capt. P. W. Trott of the British tank S. S. *Tascalusa*, a weather report covering the voyage of that vessel from Hongkong to San Francisco, March 6–30, 1921. Embodied therein were weather reports received by wireless from other vessels.

This report is of especial interest as showing the possibilities of the exchange of weather observations by vessels at sea, from which deductions can be made as to the location and movement of storm centers and the character of weather to follow.

It is not stated whether any attempt was made to chart the observations received by the *Tascalusa*.

The report is published herewith in the hope that it will serve to stimulate the officers of other ships to collect and make use of such information—*F. G. T.*

British S. S. Tascalusa, weather report North Pacific, Mar. 6 to 30, Hongkong to San Francisco; also weather reports by wireless from other vessels.

Date.	App. T.	Name of ship.	Position. Latitude	Position. Longitude.	Wind direction.	F.	Current set.	Direction (hours).	Barometer.	Temperature (air F.).	Remarks.
			N.	E.							
Mar. 6	Noon	Tascalusa	22¼	114½	ene.	4	wsw.	[1] ½	30.30	62	Overcast and dull.
7	do.	do.	[2]	[2]	ne.	6			30.30	58	Rough, northerly sea; dull.
8	do.	do.	25½	121	ne.	5			30.25	63	Rough, cloudy.
9	do.	do.	27½	124¾	nne.	5			30.33	64	Rough, clear.
10	do.	do.	30	129	e.	2	ene.	½	30.28	67	Fine, clear weather.
11	do.	do.	32¾	133¾	sse.	6	ene.	1¼	30.20	62	Rough sea, overcast.
11	8 p. m	Broad Arrow	37¼	133¼	ssw.	2	ene.	1½	30.10	55	Northerly swell, cloudy.
12	Noon	Tascalusa	34¼	138¾	ssw.	6			29.82	62	Continuous rain.
12	8 p. m.	Broad Arrow	40	138	ne.	5			29.64	40	Rough sea, overcast.
13	Noon	Tascalusa	35½	143	nw.	2			29.65	62	Heavy confused seas.
13	8 p. m	Broad Arrow	42	141½	s.	2			29.57	38	Easterly swell.
14	Noon	Tascalusa	36½	148	nw.	3			29.72	48	Heavy confused sea.
14	8 p. m	West Cajoot	36	146½	nw.	3			29.56	47	Clear.
14	do.	Broad Arrow	41½	146½	w.	6			29.50	35	Moderate sea, clear.
15	Noon	Tascalusa	37¼	153¼	sw.	4	ne.	1	29.45	53	Moderate sea, cloudy.
15	8 p. m	West Cajoot	37½	153¼	sw.	7			28.92	52	High sea; squally.
15	12 p. m	Tascalusa	38	156	nw.	12			29.03	50	Terrific squalls; thunder and lightning.
16	8 a. m	do.	38	157	wsw.	8			29.44	46	Heavy squalls.
16	do.	Broad Arrow	41½	152½	w.	8			29.14		Heavy snow squalls.
16	Noon	Tascalusa	38	158½	w.	8			29.50	47	Frequent hail squalls.
16	8 p. m.	Broad Arrow	42	158	w.	9			29.04	37	Hail and snow squalls.
16	do.	Eldridge	45½	163½	w.	10			28.63	33	Do.
16	do.	Kigo	38¾	150	nw.	7			29.82	42	Do.
16	do.	S. S.	38¼	179½	se.	7			29.62	39	Rough sea; bar. falling.
17	Noon	Tascalusa	38	163½	w.	7			29.61		Clear and squally.
17	8 p. m	West Ivan	49	[3] 177½	s.	4			29.56	42	Do.
17	do.	Algonquin	47	161	se.	3			29.85		Fine and clear; northeasterly swell.
17	do.	Alaska Maru	41½	179½	wnw.	6			29.58	53	Clear.
17	do.	Broad Arrow	42½	162¾	w.	8			29.18	36	Squally.
17	do.	Eldridge	47	168¾	SE.	5			28.57	38	O. R., rough sea.
17	do.	SS	40	155	nw.	5			29.77	40	O. R., heavy northwest seas.
18	do.	Tascalusa	38	171	w.	6			29.80	51	Weather moderating.
18	do.	SS	41	160	nw.	3			29.75	38	Overcast.
18	do.	do.	23½	169½	wsw.	1			29.82	76	Westerly swell.
18	do.	do.	48	174½	sw.	7			28.95	39	Wind increasing, barometer rising.
18	do.	do.	49	172	w.	4			28.92	38	Moderate cross sea.
18	do.	do.	43	168	w.	4			29.51	37	Moderate sea, cloudy.
18	do.	do.	39½	172	wnw.	4			29.58	45	Rain squalls.
19	do.	Tascalusa	38	176	sse.	7			29.62	57	Heavy rain; O. confused sea.
19	do.	SS	43½	173½	w.	1			29.56	42	O., westerly sea.
19	Noon	do.	34	170	s.	5			29.81		O. R., rough sea.
20	8 p. m	Tascalusa	38¾	179½	sse.	7			29.53	56	Heavy rain, confused sea.
20	do.	SS	47	[3] 176	se.	4			29.79	57	Squally, moderate sea.
20	do.	do.	31½	168¾	s.	3					Foggy.
20	do.	do.	44	171	nnw.	3			29.79	36	Cloudy, northwest sea.
20	do.	do.	44	[3] 179½	w.	2			29.72	42	Do.
20	do.	Tascalusa	38½	175	nw.	6			30.08	50	Wind moderate; p. m., F. G.
20	do.	SS	40	169½	w.	7			29.69	54	Heavy southwest sea.
20	do.	do.	44½	175½	wnw.	10			29.49	38	Heavy sea, O. C.
20	do.	do.	31½	172¾	wn.	4			30.18		Smooth sea.
20	do.	do.	44¼	176½	nw.	6			30.12	38	Clear moderate northwest sea.
21	do.	Tascalusa	38½	170	nw.	5			30.55	55	High northwest swell; Clear.
21	do.	SS	31	176¼	e.	3			30.43	58	Do.
21	do.	do.	44½	170	wnw.	8			30.27	41	Rough sea.
21	do.	do.	44½	177½	sw.	3			30.42	46	Moderate southwest sea.
21	do.	do.	50	160½	ese.	2			29.22		Barometer rising.
22	do.	Tascalusa	38¼	165	nnw.	6			30.55	52	Heavy northerly swell.
22	do.	SS	44¾	165	nw.	6			30.49	43	Heavy, clear.
23	do.	Tascalusa	38½	160	ne.	4			30.48	51	Clear.
23	do.	SS	39½	151	ne.	5			30.19	48	Rain squalls.
23	do.	do.	45½	159	ne.	1			30.64	46	Smooth sea.
23	do.	do.	44½	166	var.				30.63	40	O. F.
24	do.	Tascalusa	38¾	156	ene.	5			30.25	52	High northeast swell.
24	do.	SS	39½	146	ene.	6			30.10	51	Squally.
24	do.	do.	44¼	153½	e.	3			30.59	45	Easterly swell.
24	do.	do.	50	142	wsw.	4			30.52	42	O. M.
25	do.	Tascalusa	38¼	152	se.	3			30.21	57	High easterly swell.
25	do.	SS	43½	149	ese.	4			30.39	48	Dense fog, head swell.
25	do.	do.	45	154	ese.	4			30.29	47	O. F.
25	do.	do.	49	137	wnw.	3			30.43	46	
25	do.	do.	49½	134½	wnw.	3			30.55		
26	do.	Tascalusa	38¼	148½	se.	6			30.07	58	Rain; high southerly sea.
26	do.	SS	43¼	149	sse.	5			30.17		Rain; moderate sea.
26	do.	do.	43	144	se.	4			30.40	50	Overcast.
26	do.	do.	45	148	sse.	5			30.23	47	O. M. F.
27	do.	Tascalusa	38¼	145	se.	4			30.32	56	O. D. M.
27	do.	SS	44½	142½	s.	3			30.34	38	O. D. M., southerly swell.
28	do.	Tascalusa	38½	141	e.	3			30.45	54	C., smooth sea.
28	do.	SS	41	133	ne.	4			30.20	51	Do.
28	do.	do.	43	137	ne.	3			30.58	47	O., smooth sea.
29	do.	Tascalusa	38¼	136	e.	3			30.36	52	O. C.
29	do.	SS	41½	131½	nne.	4			30.38	47	O. C.
30	do.	Tascalusa	38	130	nne.	4	s.	[1] ½	30.20	52	Cloudy, northeasterly swell.

[1] Minute. [2] Formosa, Ch. [3] West.

NOTE.—Where only the entry "SS." occurs, the name of the reporting vessel is not given (Ed.).

NOTES, ABSTRACTS, AND REVIEWS.

THE CLASH OF THE TRADES IN THE PACIFIC.

By C. E. P. BROOKS and H. W. BRABY.

[Abstracted[1] from Quarterly Journal of the Royal Meteorological Society, Vol. XLVII, No. 197, January, 1921.]

The area considered lies between latitudes 5° S. and 12° N. and between longitudes 150° W. and 150° E. Regular observations were taken at several small islands and, in this study, were supplemented by mean values for the open ocean, published on the pilot charts of the United States Hydrographic Office. The discussion is based principally upon conditions prevailing during the period January to June. East of 180° longitude the Trades meet at a small angle and moderate rainfall occurs. Most of this rain falls with a NE. wind; the explanation seems to be that the SE. Trade, being warmer, rises over the NE. Trade. [Query: Does this SE. Trade continue northward as the antitrade?] Occasionally rain occurs with a westerly wind. The reason for this is not clear, but the authors suggest that the westerly winds may be produced by eddies and are therefore local in character. West of 180° longitude the Trades meet at a large angle, almost at right angles, in fact. They do not differ materially in density and therefore mix and form a great mass of rising air. As a result heavy rainfall occurs, much heavier than farther east. The belt along which the Trades meet is of course one of low pressure, with lowest values in the west, where the angle between the two wind systems is large. The exact location of the lowest pressure varies, and it is found that the amount of rainfall is closely associated with the movements of this "mobile center of action." When it is located well to the west, dry weather results; when it moves eastward, increasing rain occurs.

In an addendum the authors point out the parallelism between the "Equatorial Front," formed by the meeting of the Trades, and Bjerknes's "Polar Front," but remark that the former never has the wavy form or the undulating motion, both of which are characteristic of the latter.—*W. R. G.*

[1] For other abstracts see *Nature* (London), Nov. 25, 1920, p. 425; *Meteorological Mag.*, December, 1920, p. 248.

RECOVERY OF SOUNDING BALLOONS AT SEA.

The recent addresses of His Serene Highness, Albert I, Prince of Monaco, before the American Geographical Society in New York City and the National Academy of Sciences in Washington, in which he discussed the aerial soundings made from his yacht, the *Princesse Alice*, recall the interesting methods employed in recovering the instruments which have ascended to high altitudes and descended again to the surface of the sea. The methods employed in making sounding-balloon ascents at sea consist essentially in sending aloft two balloons in tandem, one more fully inflated than the other. Below hangs the meteorograph and below that a float which, upon returning to the surface, acts in conjunction with the balloon, to keep the instruments above the water and to signal the location of the apparatus. The more fully inflated balloon bursts, thus allowing the other balloon, instruments, and float to descend to the surface of the sea. But how is the location of the apparatus to be determined?

This question was answered in a simple and quite satisfactory manner by Ensign Sauerwein of the *Princesse Alice*.[1] By charting the course of the ship upon the map, and by noting with a theodolite the altitude and azimuth of the balloon, it was possible to determine with precision the distance from the ship of a vertical dropped from the point where one of the balloons burst. In order to ascertain the point where the other balloon will reach the sea, one must know the altitude of bursting, the rate of descent, and the winds at all levels traversed. Of these three factors, the first can be computed from the rate of ascent of the balloon, a matter to be determined by experiment, and the time of bursting can be observed through the theodolite; the rate of descent can be quite accurately computed by knowing the weight of the apparatus and the resistance of the falling mass; the winds encountered on the descent are assumed to be the same as were encountered on the ascent, which is to say that the direction of the point where the balloon will touch the surface is in the same direction as the resultant line joining the starting and bursting points of the balloon. It should be remembered, of course, that the vessel must steam in the direction the balloon is traveling, and thus be able to retain the balloon in sight under ordinary conditions for the entire flight.

It is recognized that this is only an approximation, but the objections which can be raised against it on such a score are answered by the significant fact that the scheme works, and has been successfully employed by the investigators above mentioned. Cloudiness, obviously, introduces difficulties. The balloon when riding above the waves is a conspicuous object, for it usually stands from 100 to 150 meters above the surface and is painted a conspicuous color, thus rendering it visible for many miles. De Bort remarks that in general the above method was sufficiently accurate to bring the ship within 7 or 8 miles of the point of descent, a limit within which the balloon was easily visible. It was only necessary upon sighting the balloon to steam toward it and, with a specially prepared hook, catch hold of the light cord and draw the apparatus aboard the vessel.—*C. Le Roy Meisinger.*

[1] S. A. S. le Prince de Monaco: Sur les lancements de ballons sondes et de ballons pilotes au-dessus des océans. *Comptes Rendus*, Sept. 11, 1905, pp. 492–493. This method of recovering balloons at sea was also used about the same time by Teisserenc de Bort and Lawrence Rotch. Cf. Étude de l'atmosphère marine par sondages aériens Atlantique moyen et région intertropicale. *Travaux Scientifiques de l'Observatoire de Météorologie Dynamique de Trappes*, Paris, 1909, pp. 49–50.

SIMULTANEOUS VARIATIONS OF TEMPERATURE AND WIND SPEED ON THE EIFFEL TOWER.[1]

By R. DONGIER.

[Abstracted from *Comptes Rendus* (Paris Acad.), Mar. 14, 1921, pp. 699–701.]

By an analysis of the temperature and wind observations made at the several stages of Eiffel Tower and at the Bureau Central, it is found that there are times when there are very rapid successive fluctuations of temperature at the top of the tower accompanied by similar fluctuations of wind speed. The wind suddenly increases from gentle to almost squall force, there is a drop of humidity, and the temperature fluctuates, as noted above. Upon investigation it is found that there is a cold surface layer being overridden by a warmer wind of greater force. There is no mixing of the air, but the

[1] Les oscillations simultanées de la température et du vent au sommet de la Tour Eiffel et leur relation avec la surface directrice (Bjerknes) d'une dépression.

friction at their interface produces waves which cause the fluctuations of temperature and wind speed. The drop in humidity is occasioned by the displacing of the cold air by warm.

All this is in accordance with the views of Bjerknes [2] on the passage of the "steering surface" (*surface directrice*) which occurs in the front of a cyclone.—*C. L. M.*

[2] Bjerknes, J.: Uber die Fortbewegung der Konvergenz und Divergenzlinien. *Meteorologische Zeitschrift*, 1917, pp. 10-11.

AMOUNT AND COMPOSITION OF RAIN FALLING AT ROTHAMSTED.

By E. J. RUSSELL and E. H. RICHARDS.

[Abstracted from *The Journal of Agricultural Science*, London, October, 1919, vol. 9, pp. 309-337.]

Agricultural chemists of the last generation expended a great deal of energy in investigating the problem of whether or not plants could assimilate free nitrogen from the air. An auxiliary problem concerned itself with the source of nitrate and ammonia: Whether they could be supplied in sufficient quantity by the air and rain, or whether artificial supply by fertilizers was necessary. In more recent years the investigation has been continued, not in its original form, but in its relation to atmospheric pollution. The authors of this article have thus investigated the rainfall for Rothamsted for the 10 years following 1905.

The rain water was first studied with respect to the content of ammoniacal nitrogen and then with respect to nitric nitrogen, and it was found that up to 1910 both forms of nitrogen varied in amount directly as the rainfall, the former in about twice as great amounts as the latter. But since 1910, the quantity of nitric nitrogen has appeared to have no simple relationship to the rainfall. The actual amount of ammoniacal nitrogen was about 2.64 pounds per acre, and its monthly fluctuations appear to follow the rainfall closely, being greatest between May and August and least between January and April.

The sources of ammonia are thought to be three, chiefly, the ocean, the soil, and pollution from cities. Since neither the first nor the last seem adequate to account for all the ammonia, the soil itself must generate an appreciable amount. This conclusion appears to be justified because of the direct relation existing between the ammonia content of the soil and biochemical activity. Moreover, the close relationship between ammoniacal and nitric nitrogen suggests either a common origin or the production of nitric compounds from ammonia.

The chlorine content of rain is such as to bring down 16 pounds per acre per year. While there is a close relation between chlorine content and rainfall, there is a decided increase in quantity in the winter months, which is attributed to the transportation of chlorine from the ocean by the gales prevalent during those months. Some of it, however, may come from fuel.

Both chlorine and nitric nitrogen have shown a steady increase from the first measurements in 1888 to the present time. The ammonia content has fallen off. The total of ammoniacal and nitric nitrogen, however, has remained about constant, indicating that perhaps the former source of ammonia is now producing nitric acid. Perhaps the modern gas ranges and grates have produced this effect.

It was found that 66.4 pounds of dissolved oxygen per acre was brought down by rain annually.

The difference of content of winter and summer rain, the former being rich in chlorine and low in nitrogen, and the latter having the relation reversed, makes it seem that the formation of rain during the two seasons differs. Since the winter rain so closely resembles Atlantic rain, it is thought that summer rain may be caused by evaporation of water from the soil and condensation at higher altitudes than in the case of winter rain.—*C. L. M.*

ATMOSPHERIC POLLUTION.

(Sixth Report of the Committee for the Investigation of Atmospheric Pollution, Meteorological Office, London, 1921.)

[Abstract of review by Alexander McAdie in *Science*, New York, Apr. 22, 1921, pp. 389-391.]

In a previous REVIEW [1] is an abstract of the Fourth Report of the Committee for the Investigation of Atmospheric Pollution containing a detailed analysis of the solids collected in the atmosphere of London, Newcastle, and Malvern, the two latter stations showing, respectively, the greatest and the least amounts of pollution.

In all, 29 gages are in operation, distributed as follows: Birmingham, 3; London, 8; Glasgow, 9; Southport, 2; and 1 each at Kingston, Malvern, Newcastle, Rochdale, Rothamsted, St. Helen's, and Sterling.

The following data are given in this report: (1) Monthly deposits for the two stations representing high and low deposits; (2) total solids deposited monthly at all stations; (3) monthly deposits for summer-half years, i. e., April to September, 1918 and 1919; (4) mean monthly deposits for winter-half years, i. e., October to March, 1918–19, and 1919–20; (5 and 6) classification of stations according to amounts of elements; (7 and 8) totals of classified stations for each element of pollution; (9) comparison of mean monthly deposit during summer and winter; (10) average deposit of each element for each month for two London and four Glasgow stations; also six summaries and analyses.

The table below (somewhat abridged) gives the mean monthly deposits at selected stations.

TABLE 1.—*Mean monthly deposit in metric tons per square kilometer.*

Meteorological office	8.43
Finsbury Park	10.78
Ravenscourt Park	14.09
Southwark Park	15.35
Hasketh Park	6.41
Woodvale Moss	5.34
Malvern	3.17
Bellahouston Park	8.87
Botanic Gardens	10.91
Queens Park	8.01
Richmond Park	12.15

As might be expected the greatest amount of tar deposit occurred in the winter months, when domestic fires are in constant operation. The results of the investigation also seem to indicate that wind plays an important part, high winds sweeping away much of the suspended matter, thus preventing it from being deposited near the source.

Automatic filters holding 24-hour disks were employed. From a large number of records made from these disks in London there appears to be a definite cycle during the 24 hours in the distribution of impurities. Thus from midnight to 6 a. m. the air is practically clear of impurity, very little being recorded except during fogs. At about 6 a. m. when fires are lit, there is an increase until 11 a. m. From 11 a. m. to 10 p. m. there is little variation. After the latter hour, however, there is a rapid decrease to midnight when the minimum period begins.

In considering the feasibility of utilizing standard rain gages in the measurement of solid deposits, the

[1] MONTHLY WEATHER REVIEW, November, 1919, 47: 806-807.

committee found it practically impossible to estimate accurately the quantity of tar and sulphates present; and these indicate the origin of the deposit. The difficulty experienced was the dissolution of the metal of which the rain gages is constructed.—*H. L.*

ENGINEERING APPLICATIONS OF STATISTICAL WEATHER DATA.

By REID DAVIES.

[Abstract of paper, "Some temperature probabilities for March," published in *The Heating and Ventilating Magazine, New York, February, 1921, pp. 37-39.*]

During the past 15 years *The Heating and Ventilating Magazine* has been publishing, monthly, charts showing the weather conditions in several of the larger cities in this country [cf. charts for December, 1920, ibid., pp. 50-51]. These charts find their principal value in connection with analysis of heating-plant operation, coal consumption, etc. Obviously they are of little value in connection with the design of new installations because the weather conditions of a given month will never be exactly duplicated in any succeeding month. Of distinct value, however, from the design standpoint, would be knowledge of the maximum and minimum and average conditions over a period of years sufficiently long to make the figures reliable for inductive purposes.

A series of seven charts of curves is published each month for New York, Boston, and Chicago, showing *for each day:* The highest temperature for the entire period of observations, the highest mean temperature, the average maximum temperature, the average mean temperature, the average minimum temperature, the lowest mean temperature, and the lowest temperature ever reached.

While this discussion is confined to the curves for New York City, there is almost equal application to the charts for the other cities mentioned. An engineer, figuring on the cost of operating a heating plant during March, can see from the chart that the daily average mean temperatures remain well below 50° throughout the month, and average for the entire month 38°. This indicates that during March sufficient coal will have to be consumed to provide for a continuous heating of the outside air from 38° to the desired inside temperature. The curves also show the possibility that on some days during March, no heating will be required, as well as equal possiblity that on some days considerably more heating will be required, with corresponding fuel consumption.

Obviously the month of March does not show the maximum heating requirement of a system, as December, January, and February temperatures will fall below those of March, but where an installation comprises several heating units, the March chart will indicate how many are likely to be required in operation during that month. The chart is more reliable for a period of years than for any one year, and as a heating installation is made for use over a period of years, the use of the chart will indicate probable operating characteristics of the installation during its period of service.

Temperature records for March.

	New York.	Boston.	Chicago.
	° F.	° F.	° F.
Record high temperature	78	78	80
Highest daily mean temperature	66	62	70
Average maximum temperature	45	44	42
Average mean temperature	38	37	35
Average minimum temperature	30	30	29
Lowest daily mean temperature	9	−1	1
Record low temperature	3	−8	−12

—*H. L.*

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SOLAR OBSERVATIONS.

SOLAR AND SKY RADIATION MEASUREMENTS DURING MARCH, 1921.

By HERBERT H. KIMBALL, Meteorologist.

[Solar Radiation Investigations Section, Washington, Apr. 28, 1921.]

For a description of instruments and exposures, and an account of the methods of obtaining and reducing the measurements, the reader is referred to this REVIEW for April, 1920, **48**: 225.

From Table 1 it is seen that the solar radiation intensities measured very close to normal for March at all the stations.

At Lincoln, a marked diminution in solar radiation intensities after noon of the 31st is due to a change in the wind direction which brought smoke from the city over the station at the University farm 2½ miles away.

Table 2 shows an excess in the radiation received from the sun and sky at Washington, a decided deficiency at Madison, and close to the normal amount at Lincoln.

Skylight polarization measurements obtained on eight days at Madison give a mean of 69 per cent and a maximum of 72 per cent on the 17th. At Washington, skylight polarization measurements obtained on four days give a mean of 54 per cent and a maximum of 64 per cent on the 18th. The Madison values are above the averages for March, and the Washington values are slightly below the average. After the 18th the polarimeter at Washington was undergoing repairs, and no observations were obtained until the first of the next month.

TABLE 1.—*Solar radiation intensities during March, 1921.*

[Gram-calories per minute per square centimeter of normal surface.]

Washington, D. C.

Date.	8 a. m. 75th meridian time. e.	78.7° A. M. 5.0	75.7° A. M. 4.0	70.7° A. M. 3.0	60.0° A. M. 2.0	0.0° *1.0	60.0° P. M. 2.0	70.7° P. M. 3.0	75.7° P. M. 4.0	78.7° P. M. 5.0	Noon. Local mean solar time. e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Mar. 1	5.16				0.96		0.96				4.57
10	2.87				1.32		1.16	0.87	0.75	0.61	2.74
11	4.57	0.78	0.92	1.06	1.22				0.91		3.30
14	7.29			0.71	0.91						8.18
16	9.14						1.07	0.80	0.65	0.63	10.97
18	3.99		0.92	1.04	1.27	1.44	1.27				3.00
23	3.45		0.81	0.95	1.10	1.29					4.17
25	9.14					1.38	1.10	0.90	0.76		10.59
29	1.78			1.05	1.28	1.45	1.06	0.80	0.66	0.57	1.96
Means		(0.78)	0.88	0.96	1.15	1.39	1.10	0.84	0.75	0.60	
Departures		+0.07	+0.06	+0.00	−0.01	−0.03	−0.03	−0.09	−0.05	−0.10	

Madison, Wis.

Date.	8 a. m.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon.
Mar. 2	4 95			1.15	1.32	1.52					4.75
3	1.68					1.53	1.36	1.22			1.37
9	2.36						1.35				1.68
16	1.78				1.31	1.52					2.87
17	4.57				1.20		1.09	0.83			5.36
28	1.19					1.60	1.35	1.21	1.06	0.93	1.32
29	2.06					1.46	1.18				2.74
30	3.63				1.13						4.95
Means				(1.15)	1.24	1.53	1.27	1.09	(1.06)	(0.93)	
Departures				−0.05	−0.09		−0.06	+0.02	−0.01		

Lincoln, Nebr.

Date.	8 a. m.	5.0	4.0	3.0	2.0	*1.0	2.0	3.0	4.0	5.0	Noon.
Mar. 3	3.00			1.06	1.35	1.51	1.29	1.09	0.95	0.86	2.87
9	1.78					1.56	1.24	1.09	0.97	0.80	4.17
10	3.30			1.02	1.22	1.45					3.63
11	3.00							0.94	0.79	0.63	3.45
16	2.74				1.28						8.81
22	2.36			1.10	1.29	1.51	1.21	1.04	0.87	0.72	2.87
25	5.36				1.27	1.52					3.63
28	1.68					1.45	1.22	1.02	0.86	0.75	3.99
29	3.00				1.26	1.52					3.45
31	2.74		0.91	1.10	1.31	1.55	1.19	0.93	0.78	0.64	3.30
Means			(0.91)	1.07	1.28	1.51	1.23	1.02	0.87	0.73	
Departures			−0.01	−0.02	−0.02		−0.03	−0.06	−0.06	−0.05	

TABLE 1.—*Solar radiation intensities during March, 1921*—Continued.

Santa Fe, N. Mex.

Date.	8 a. m. 75th meridian time. e.	78.7° A. M. 5.0	75.7° A. M. 4.0	70.7° A. M. 3.0	60.0° A. M. 2.0	0.0° *1.0	60.0° P. M. 2.0	70.7° P. M. 3.0	75.7° P. M. 4.0	78.7° P. M. 5.0	Noon. Local mean solar time. e.
	mm.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*mm.*
Mar. 16	3.00			1.36	1.51	1.67	1.45	1.31	1.18	1.09	1.78
17	2.49		1.25	1.37	1.50	1.73	1.52	1.36	1.20	1.08	2.49
23	3.63			1.16	1.40	1.64	1.47	1.31	1.20	1.08	1.96
24	2.26			1.27	1.37	1.59					2.36
Means			(1.25)	1.29	1.44	1.66	1.48	1.33	1.19	1.08	
Departures			+0.04	−0.02	−0.01	+0.05	+0.07	+0.06	+0.07	+0.03	

TABLE 2.—*Solar and sky radiation received on a horizontal surface.*

Week beginning.	Average daily radiation. Washington.	Madison.	Lincoln.	Average daily departure for the week. Washington.	Madison.	Lincoln.	Excess or deficiency since first of year. Washington.	Madison.	Lincoln.
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Feb. 26	285	216	369	− 6	− 69	+22	−450	−2,407	−1,041
Mar. 5	326	217	372	+12	− 95	− 1	−365	−3,171	−1,048
12	408	216	318	+69	−117	−81	+120	−3,893	−1,617
19	364	271	417	+ 6	− 81	+ 2	+165	−4,459	−1,605
25	441	389	472	+66	+ 19	+71	+629	−4,324	−1,251

* Extrapolated.

MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE, FEBRUARY, 1921.

By C. G. ABBOT, Assistant Secretary.

[Smithsonian Institution, Washington, May 2, 1921.]

In continuation of preceding publications, I give in the following table the results obtained at Montezuma, near Calama, Chile, in February, 1921, for the solar constant of radiation. The reader is referred to this REVIEW for February, August, and September, 1919: **47**, for statements of the arrangement and meaning of the table.

The unusually small number of observations reported for January and February were due to the unprecedentedly cloudy weather of these months. In a telegram, it is reported that the weather of March was more favorable.

Date.	Solar constant.	Method.	Grade.	Transmission coefficient at 0.5 microns.	Humidity. ρ/ρ s.c.	Humidity. V. P.	Humidity. Rel. hum.	Remarks.
1921. P. M.	*cal.*					*cm.*	*Per cent.*	
Feb. 11	1.962	$M_{1.04}$	S−	0.857	0.506	0.34	13	Cirri scattered about sky.
	1.953	$M_{1.02}$						
	1.956	W. M						
A. M. 12	1.947	$M_{1.13}$	S−	.857	.583	.55	28	Cirri scattered over north and east.
P. M. 21	1.960	$M_{1.06}$	S−	.856	.504	.60	22	Clouds scattered about sky.
	1.958	$M_{1.03}$						
	1.959	W. M						
A. M. 24	1.942	$M_{1.30}$	S..	.855	.487	.57	32	Cirri in east preventing earlier observations.
	1.950	$M_{1.29}$						
	1.946	W. M						
25	1.960	$M_{1.04}$	S..	.857	.557	.71	26	Cumuli over high peaks.
	1.961	$M_{1.03}$						
	1.960	W. M						
26	1.960	$M_{1.42}$	S..	.855	.494	.69	41	Few clouds low in east.
	1.951	$M_{1.30}$						
	1.955	W. M						
28	1.971	$M_{1.10}$	S−	.850	.626	.71	39	Clouds over western and eastern horizon.
	1.973	$M_{1.07}$						
	1.972	W. M						

WEATHER OF THE MONTH.

WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month was very much above the normal at land stations on the coasts of Newfoundland, Canada, New England, the Bermudas, and the Azores. It was slightly higher than usual along the south Atlantic coast of the United States and the Gulf of Mexico, as well as in the southern portion of the British Isles, and nearly normal or slightly below at certain stations in the West Indies and in northern European waters.

Fog was apparently rare on the steamer lanes and in European waters, while it was observed on from 3 to 5 days in different 5-degree squares on the Banks of Newfoundland and along the American coast, which is considerably below the normal for that locality.

The number of days with winds of gale force was not far from the normal over the greater part of the ocean, being slightly below in some sections and above in others.

With a few exceptions the weather over the ocean during the first decade of the month was moderate in character, with the Azores HIGH well developed, and the pressure well above the normal over the greater part of the steamer lanes. On the 10th there was a well-developed LOW central near St. Johns, N. F., and a number of vessels along the American coast, between Nantucket and Hatteras, experienced moderate gales with comparatively high barometric readings. The following storm logs are from the few vessels that experienced heavy weather during the period from the 1st to the 10th.

American S. S. *Ampetco:*

Gale began on the 3d, wind WSW. Lowest barometer 29.87 inches at 11 p. m. on the 3d; position, latitude 48° 36′ N., longitude 31° 53′ W.; shifts of wind near time of lowest barometer, WSW.-W.-WNW. Highest force of wind 10, WSW.

British S. S. *Kabinga:*

Gale began on the 4th, wind NW. Lowest barometer 29.89 inches at noon on the 4th; position, latitude 40° 44′ N., longitude 67° 50′ W. End of gale on the 5th, wind N. Highest force 9, NW.; shifts NW.-W.

British S. S. *Imperator:*

Gale began on the 4th, wind W. Lowest barometer 29.64 inches at midnight on the 4th; position, latitude, 41° 06′ N., longitude 57° 10′ W. End on the 5th, wind NW. Highest force of wind 9, S.; shifts S.-W.-NW.

American S. S. *Ampetco:*

Gale began on the 5th, wind SSW. Lowest barometer 29.65 inches at 2 p. m. on the 6th; position, latitude 46° 50′ N., longitude 40° 32′ W. End of gale on the 6th, wind NW. Highest force of wind 11, W.; shifts SW.-W.-WNW.

American S. S. *Ampetco:*

Gale began on the 7th, wind SSW. Lowest barometer 30.12 inches at midnight on the 7th; position, latitude 44° 55′ N., longitude 47° 41′ W. End of gale on the 8th; wind WSW. Highest force 9, WSW.; shifts WSW.-NNW.

American S. S. *W. M. Burton:*

Gale began on the 9th, wind NW. Lowest barometer 30.08 inehes at 4 a. m. on the 10th; position, latitude 37° N., longitude 75° W. End at 9 a. m. on the 10th, wind NNE. Highest force 10, N.; shifts, steady from N.

As can be seen from the above logs, the *Ampetco* was exceptionally unfortunate, as she encountered three distinct disturbances in six days, while storm reports were received from only three other vessels during the first decade of the month.

From the 11th to the 17th there was a disturbance over the eastern portion of the steamer lanes; the storm area extended from the 45th meridian to the European coast, north of the 40th parallel, and moved but little during this period. Unfortunately there were unusually few reports received from the northeastern section of the ocean, and it was impossible to determine the center or northern limits of this disturbance. From the 13th to the 16th unusually low barometer readings were recorded at the land stations in Iceland, and during that period the center of the LOW was probably not far from that island.

Charts IX, X, XI, XII, and XIII show the conditions for March 12, 13, 14, 15, and 16, respectively.

Storm logs follow:

British S. S. *Strathearn:*

Gale began on the 11th, wind SW. Lowest barometer 29.26 inches at noon on the 11th, wind W., 7; position, latitude 48° 08′ N., longitude 30° 32′ W. Same reading at 9 a. m. on the 14th, wind WSW.; position, latitude 45° 14′ N., longitude 33° 26′ W. End of gale on the 15th, wind WSW. Highest force of wind 12, WSW.; shifts W.-WSW.-W.

British S. S. *Mackinaw:*

Gale began on the 11th; wind W. Lowest barometer 29.33 inches at 7 a. m. on the 12th, wind SSW., 10; position, latitude 49° 27′ N., longitude 12° 30′ W. End of gale on the 17th, wind NW. Highest force of wind 12, W.; shifts WSW.-W.

American S. S. *Editor:*

Gale began on the 13th; wind SW. Lowest barometer 29.48 inches at 8 a. m. on the 14th, wind WSW.; position, latitude 43° 20′ N., longitude 35° 10′ W. End on the 17th. Highest force of wind 10, W.; shifts SSW.-W.-WNW.

Danish S. S. *Oscar II:*

Gale began on the 14th, wind SSW. Lowest barometer 28.72 inches at 9 a. m. on the 15th, wind SW.; position, latitude 57° 45′ N., longitude 15° 30′ W. End on the 18th. Highest force of wind 10, SW.; shifts not given.

Swedish S. S. *Stockholm:*

Gale began on the 15th, wind NW. Lowest barometer 29.59 inches at noon on the 16th, wind NW.; position, latitude 50° 21′ N., longitude 37° 15′ W. End of gale on the 17th, wind WNW. Highest force of wind 10, NW.; shifts not given.

On the 18th there was a moderate disturbance, central about 200 miles south of Halifax, N. S. This LOW drifted slowly eastward, increasing slightly in intensity, and on the 19th a number of vessels between the 40th and 60th meridians encountered moderate to strong gales, while others in the same region reported weather of less severity.

The storm log from the American S. S. *Calvert* follows:

Gale began on the 18th, wind SW. Lowest barometer 29.35 inches at 2 p. m. on the 18th, wind S., 12; position, latitude 39° 30′ N., longitude 59° W. End of gale on the 20th, wind NNE., 6. Highest force of wind 12, S.; shifts SW.-S.-SW.-S.-NW.

Extract from Daily Journal of the Dutch S. S. *New York:*

March 18: Good weather, wind shifting from NNW. through east to SSW. At 10 a. m. wind and sea increasing, barometer at noon, 29.75 inches, wind SSW., 6. At 2.40 p. m., 29.49 inches, SW., 11. At 2.50 p. m. the wind was blowing with considerable force, accompanied by heavy hail squalls, lightning, and thunder. At 3 p. m. barometer rising and wind decreasing. During the whole night westerly winds, force 8. At 7 p. m., barometer 29.75 inches. Noon position, latitude 39° 02′ N., longitude 59° 18′ W.

March 19: Strong westerly gales and high seas. During the whole day rain squalls.

From the 21st to the 26th reports were received from vessels that encountered westerly gales in the region

between the 20th meridian and the coast of Scotland, with the pressure at Iceland considerably below the normal, the barometer at Reykjavik reading as low as 28.39 inches on the 23d. Storm logs are as follows:

British S. S. *Malvern Range:*

Gale began on the 20th, wind S. Lowest barometer 29.58 inches at 3 a. m. on the 23d, wind WSW., 11; position, latitude 58° 20′ N., longitude 16° W. End on the 23d, wind variable. Highest force of wind 11, WSW.; shifts S.-W.-SW.-SSE.-WSW., variable.

British S. S. *Malvern Range:*

Gale began on the 24th, wind NNW. Lowest barometer 29.91 inches at 4 a. m. on the 26th, wind WNW., 10; position, latitude 56° N., longitude 22° W. End of gale on the 26th, wind SW. Highest force of wind 11, W.; shifts NNW.-W.-WNW.-WSW.

On the 22d and 23d there was a well developed LOW, central near the center of the steamer lanes, the storm area extending from the 40th to 50th parallels, and from the 25th to 45th meridians. Storm logs follow:

British S. S. *Canada:*

Gale began on the 21st, wind SW. Lowest barometer 29.60 inches at 10 a. m. on the 22d; position, latitude 45° N., longitude 40° W. End of gale on the 23d, wind NW. Highest force of wind 10, SW.; shifts SW.-W.

Belgian S. S. *Gothland:*

Gale began on the 22d, wind SW. Lowest braometer 29.63 inches at 6 a. m. on the 23d, wind WNW.; position, latitude 45° 09′ N., longitude 37° 02′ W. End of gale on the 23d, wind NW. Highest force of wind 9, W. Shifts SW.-WNW.

The observer on the British S. S. *Canada* reports that at 6 a. m. March 24, near latitude 42° 37′ N., longitude 52° 16′ W., the vessel steamed through tide rips extending to the horizon in a northwesterly direction. Temperature of water on northerly side 29° F., and after passing through the line of ripples, 33° F.

A good example of the "zone of silence" is given by the observer on the British S. S. *Strathearn*, who states that on March 25, steering 182°, he heard Nantucket Shoal light vessel fog signal distant 5 miles, very faint ahead; it got louder until 2 miles away when signal ceased to be heard until on starboard beam one-half mile distant. The whistling buoy was heard at a distance of 2 miles and until well past the beam. Position checked by soundings and wireless direction stations.

On March 26 a moderate disturbance was central near latitude 40° N., longitude 42° W.

The storm log from the British S. S. *Caledonia* follows:

Gale began on the 25th, wind NE. Lowest barometer 29.90 inches at 4 p. m. on the 26th, wind N., 7; position, latitude 42° 11′ N., longitude 45° 47′ W. End of gale 4 a. m. on the 27th, wind ENE. Highest force of wind 8, NE.; shifts NE.-N.

On the 28th and 29th there was a disturbance some distance west of the coast of Scotland, although it was impossible to determine its center and extent accurately, on account of lack of observations.

Storm logs follow:

British S. S. *Malvern Range:*

Gale began on the 27th, wind NW. Lowest barometer 29.76 inches at 3 a. m. on the 28th, wind NW., 10; position, latitude 53° N., longitude 29° W. End of gale on the 29th, wind NW. Highest force of wind 10, NW.; steady from NW.

American S. S. *Satartia:*

Gale began on the 28th, wind W. Lowest barometer 29.83 inches at 2.45 p. m. on the 28th, wind NW.; position, latitude 47° 44′ N., longitude 15° 28′ W. End of gale on the 29th. Highest force of wind, 10, NW.; shifts W.-NW.

On the 29th there was a LOW central near Sydney, Nova Scotia, with moderate winds along the American coast north of the 40th parallel, while vessels between New York and Charleston encountered northerly and northwesterly gales. This disturbance moved slowly eastward and on the 30th the center was about 200 miles southeast of St. John's N. F., and moderate to strong northerly gales prevailed near the 40th parallel, between the 50th meridian and the American coast, while a few vessels west of the Bermudas also reported heavy weather. During the next 24 hours the easterly movement of this LOW was very slight, although on the 31st the storm area was considerably east of its position on the previous day and was confined between the limits of 40th and 47th parallels, and the 37th and 50th meridians.

Storm logs follow:

American S. S. *Pennsylvania:*

Gale began on the 28th, wind NW. Lowest barometer 30 inches at 7 p. m. on the 28th, wind NW., 10; position, latitude 39° 20′ N., longitude 74° 10′ W. End of gale on the 29th, wind NW. Highest force of wind, 11, NW.; shifts SW.-NW.

American S. S. *Halsey:*

Gale began on the 29th, wind NE. Lowest barometer 30.05 inches at 10 a. m. on the 29th, wind NE., 7; position, latitude 35′ M., longitude, 75′ W. End of gale at 10 p. m. on the 29th, wind NE. Highest force of wind 9, NE.; shifts S.-W.-NE.

American S. S. *Henry Steers:*

Gale began on the 30th, wind SW. Lowest barometer 29.51 inches at 6 a. m. on the 30th, wind NW., 9; position, latitude 40° 47′ N., longitude 51° 20′ W. End of gale on the 31st, wind NW. Highest force of wind 10, NNW.; shifts SW.-NW.

American S. S. *Montana:*

Gale began on the 29th, wind N. Lowest barometer 29.61 inches at 8 a. m. on the 29th, wind N., 9; position, latitude 41° 09′ N., longitude 59° 30′ W. End of gale on the 30th, wind NNW. Highest force of wind 10, N.; shifts SW.-N.-NNW.

Dutch S. S. *Kroonland:*

Gale began on the 30th, wind SSW. Lowest barometer 29.71 inches at 2 p. m. on the 30th, wind SSW., 8; position, latitude 45° 31′ N., longitude 36° 30′ W. End of gale on April 1, wind NW. Highest force of wind 9, WSW.; steady from WSW.

NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

At Midway Island pressure was above normal from the 1st to the 4th, below from the 6th to the 19th, except the 12th, and above from the 20th to the end of the month, except on the 25th. In amount the departures were moderate. At Honolulu pressure was below normal generally during the first and third decades, and below during the second decade. Here, also, the departures were moderate in amount. At Dutch Harbor pressure was almost continuously above normal, the average daily excess amounting to about 0.18 inch.

The number of gales reported was about the same as in 1919 and 1920, but they were of greater intensity. They occurred principally during the second and third decades, the weather of the first ten days of the month being relatively quiet so far as shown by the reports that have been received.

The principal disturbance of the month appears to have been one that developed to the east of Japan during the 13th and 14th through the merging of several small depressions which formed in the western part of the east China Sea and over central China on the 11th. On the 12th these cyclonic centers were disposed so as to form a trough-like depression covering the area from the northern Philippines to central Japan.

A number of vessels were involved in this disturbance, and experienced gales on several days, the wind at time

reaching hurricane force. Typical storm logs are as follows:

American S. S. *Inlay*, Capt. H. Warrer, Shanghai (Mar. 10) for San Francisco; observer, T. Olson. Gale began on the 13th; lowest barometer, 29.45 inches, at 3 p. m. of the 14th in latitude 37° 25′ N., longitude 145° E.; highest force of wind and direction, 10, W.; gale ended on the 18th; shifts, NW. to W.

British S. S. *Tachee*, Capt. I. D. Llewellyn, San Francisco (Mar. 1) for Hongkong; observer, T. Gore, third officer. Gale began and ended on 15th; lowest barometer, 29.57 inches, at 7.45 a. m., in latitude 33° 34′ W., longitude 144° 06′ E.; highest force of wind and direction, 10, W.; shifts, SW.-W.-WNW.-NW.

The *Tachee* also experienced heavy weather on the 13th and 14th.

The Japanese S. S. *Mexico Maru*, Capt. N. Yanagi, Los Angeles for Yokohama (Mar. 15), came under the influence of this depression on the 12th, being at Greenwich Mean Noon of that date in latitude 34° 35′ N., longitude 147° 23′ E. On this date there was a moderate SSE. gale and high sea, causing the vessel to labor heavily and ship water both fore and aft. The sea continued rough on the 13th with a long southwesterly swell. On the 14th there was a strong westerly gale with very high sea.

This depression apparently moved in the direction of Bering Sea as according to reports at hand it did not noticeably affect shipping east of the 165th meridian, east longitude.

About the 25th another depression of considerable intensity developed to the east of Japan, involving a number of vessels in the western part of the steamer lanes. The following storm logs show the character of this depression:

American S. S. *Montague*, Capt. G. H. Whitehead, Observer F. R. Gillan, second officer, Columbia River (Mar. 13) for Yokohama. Gale began on 26th, wind SE., 8; lowest barometer 28.20 inches (uncorrected), at 10 a. m. of 27th, in latitude 44° N., longitude 157° 20′ E.; gale ended on 27th, wind NW. by W.; highest force and direction, 11, SW.; shifts, SE.-SW.-WNW.

The *Montague* had previously experienced gales on the 19th, in longitude 174° W.; on the 20th, in longitude 178° 45′ W.; and early on the 23d, in longitude 174° 45′ E. In the afternoon of the 23d the wind increased to a strong gale. Following the storm of the 27th another storm was encountered on the 29th, in longitude 149° 50′ E. The barometer fell to 28.68 (uncorrected) at 10 a. m. of that date and the wind attained force 11, NW. by W. In the storm of the 26th–27th the barometer fell at the rate of 0.15 inch an hour and rose at the rate of 0.15 to 0.20 inch an hour.

Japanese S. S. *Africa Maru*, Capt. M. Ohyama, observer, second officer, S. Kichuchi, Yokohama (Mar. 24) for Victoria. Gale began 26th, wind ESE.; lowest barometer 28.65 inches at 10.36 p. m. of 27th in latitude 44° 21′ N., longitude 159° 45′ E.; highest force of wind and direction, 11, W., end of gale on 31st, wind W.; shifts of wind, 6 points.

On the 16th and 17th the Norwegian M. S. *Theodore Roosevelt*, Capt. Eric Thomle, Astoria (Mar. 4) for Panama, experienced a strong gale accompanied by a high sea off the Central American coast. According to Observer Sverre Sandahl, the gale began at ENE.; lowest barometer 29.96 inches at 5 a. m. of 17th in latitude 10° 50′ N., longitude 86° 45′ W.; highest force and direction, 10, WSW.

A report for March that possesses unusual interest is that of the Dutch S. S. *Baarn*, Capt. J. van Rijnbach, Valparaiso for Punta Arenas, thence toward Boston. Observer J. J. Ch. de Lange states that on March 14, before entering the strait, the weather was rainy with fresh to strong NW. breeze and some hail. When passing through the strait on the 15th there was a moderate NW. gale, with heavy rain and hail. Many tide rips were observed. The *Baarn* left Punta Arenas on the 29th with rainy weather. More tide rips were observed. On the 30th the weather was stormy, with a wild sea; wind NNW., force 9. The weather continued stormy until April 4.

During the voyage of the American S. S. *Northwestern*, Capt. Wm. Jensen, from Seattle to southwestern Alaskan ports and return, March 12–24, an exceptionally large display of northern lights was seen nearly every night while in Alaskan waters. Observer P. Christiansen states that these were probably due to the long period of clear and cold weather. This in turn may be associated with the continuously high pressure at Dutch Harbor, previously mentioned.

On March 1, at 9.45 p. m. in latitude 5° 34′ S., longitude 81° 30′ W., a large meteor was observed from the American M. S. *Sierra*, Capt. Olaf A. Janson, San Francisco for Callao. Observer John Behrsin states that its brightness surpassed that of the moon.

NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

Newfoundland.—The Newfoundland sealing fleet which went out on the 10th was unable to find the herds, owing to heavy ice.[1]

British Isles and western Europe.—As in the two preceding months, there was a marked absence of severe wintry weather over western Europe generally, and even in Sweden there was little frost after the 9th. Brief incursions of polar air were accompanied by snow in the northern districts of the British Isles at times in the first week, and in the western districts on the night of the 28th, but milder weather followed at once in every case.[1]

British Isles.—The general rainfall expressed as a percentage of the average was: England and Wales, 101; Scotland, 170; Ireland, 129; * * *.

In London (Camden Square) the mean temperature was 46.8° F., or 4.6° F. above the average. * * *[1]

France.—Paris, March 10.—All eastern and southern France is beginning to suffer from very unusual drought for this time of the year. Since the middle of January very little rain has fallen, even in the mountain districts. * * *

[1] *The Meteorological Magazine*, April, 1921, pp. 77, 79, and 84.

The result has been that the rivers are lower than at any time for 20 years at this season, and are fast approaching the lowest summer record. * * * In some parts of France authorities have had to post notices urging economy of water, as many wells have gone dry. * * *—*New York Times, March 11, 1921.*

Switzerland.—Paris, March 15.—The extraordinary drought which is causing grave damage to French farmers has also brought heavy loss to the winter sports industry in Switzerland. The bright sunshine has melted the snow at St. Moritz and other resorts until it is now necessary to mount to an altitude of 4,500 feet to find slides. * * *

Lake Geneva has almost gone dry [?] * * * Not for 90 years has it been so dry in Switzerland. Cities which depend upon hydraulic production of electricity have had to ration themselves.—*New York Times, March 16, 1921.*

India.—A telegram dated March 18 stated that famine had been declared in parts of the Bellary and Anantapur districts of the Madras Presidency.[1]

Hawaii.—Honolulu, April 16.—All islands during the month of March experienced subnormal precipitation,

with the greatest deficiency over Kauai and Oahu * * *. The means for the groups was 4.52 inches, against a 17-year mean of 7.81 inches, or only 58 per cent of the territorial 17-year mean * * *.

The mean temperature for the section exceeded the March normal over all islands of the territory, being 69.7 degrees, against a 17-year mean of 68.7 degrees. * * *—*Honolulu Times, Apr. 16, 1921.*

Peru.—The year 1920 was remarkable for its unusual rainfall. Not only was the curve for the depth of the Amazon at Iquitos higher throughout April and May than for many years, but also throughout the dry season. The lowest stage reached was some 7 feet higher than the mean minimum depth.

The exceptional inundation of April and May had destroyed much of the crops. There was a serious shortage of all staples (plaintains, beans, yucca, rice, etc.) and considerable hardship among the improvident. At no time were the sand bars of the Marañon or Amazon exposed. This of course affected the fishing industry. Seining was made much more difficult, while throw-net fishing was probably increased, due to the concentration of the mijanos, schools of fish.—*W. R. Allen in Science, Apr. 22, 1921, p. 378.*

Australia.—At the beginning of the month torrential rains fell in South Australia, causing such serious floods that ports had to be closed and traffic on the Transcontinental Railway suspended. At the same time good rain fell throughout practically the whole of New South Wales. A message received on the 17th stated that heavy rain had put out the fires in South Gippsland (Victoria).[1]

DETAILS OF THE WEATHER OF THE MONTH OF THE UNITED STATES.

CYCLONES AND ANTICYCLONES.

By W. P. Day, Observer.

Lows were much above the normal in number and well distributed by type. Secondary developments were numerous, particularly of the Colorado and Texas types. Highs were also in excess of the average, but about normal as to type. However, five of the Alberta highs moved far to the north of the normal path and their effect was only marked along the northern border. Of the remaining two, the high of the 27–30th, produced the only general cold wave.

Tables showing the number of highs and lows by types follow:

Lows.

	Alberta.	North Pacific.	South Pacific.	Northern Rocky Mountain.	Colorado.	Texas.	East Gulf.	South Atlantic.	Central.	Total.
March, 1921	6.0	2.0	1.0	1.0	5.0	3.0	1.0	......	2.0	21.0
Average number, 1892–1912, inclusive	3.6	2.1	1.1	0.3	1.9	1.3	0.4	0.3	0.7	11.8

Highs.

	North Pacific.	South Pacific.	Alberta.	Plateau and Rocky Mountain region.	Hudson Bay.	Total.
March, 1921	2.0	1.0	7.0	1.0	1.0	12.0
Average number, 1892–1912, inclusive	0.9	0.7	5.6	0.9	0.5	8.5

THE WEATHER ELEMENTS.

By P. C. Day, Climatologist and Chief of Division.

[Weather Bureau, Washington, D. C., May 2, 1921.]

PRESSURE AND WINDS.

The absence of frequent and strong pressure variations that characterized the weather during much of the past winter persisted to an unusual extent during the first spring month. As a result the weather of March, 1921, lacked much of the blustery and changeable character so commonly attributed to that month, and in many portions of the country it took on the character of the midspring season.

An examination of the charts showing the average sea-level pressure and its departure from the normal discloses, as during several months preceding, a preponderance of pressure over southern districts and a consequent flow of air from southerly into northerly regions. Likewise a review of the daily weather charts shows a marked absence of strong projections from the Polar Front, and few of the highs entering the northern boundaries of the United States penetrated extensively into the interior portions.

About the end of the first decade pressure had increased greatly in Alaska and the Canadian Northwest Provinces, and indications pointed to an extensive invasion of cold weather into the Northwest and interior districts of the United States. The full development of this high-pressure area was apparently obstructed by the appearance of cloudy, rainy weather in the central valleys, and it passed eastward over the more northern districts with only moderate decreases in temperature.

About the end of the second decade another high-pressure area of considerable magnitude entered the northwestern districts, and, while its influence extended farther southward into the Great Plains than that of the preceding decade, its extension eastward was likewise retarded by the development of cloudy, rainy weather, and it, too, passed along the northern border without large temperature changes, save over the more northern districts.

A third invasion of cold from the Polar Front occurred near the end of the last decade, and coming later in the month and after a long period of unusual warmth was, in a comparative way the severest of the month over the greater part of the country east of the Rocky Mountains, and actually so in the Mississippi and Ohio Valleys and portions of adjacent regions. This high pressure area first appeared in the Canadian Northwest on the morning of the 26th and by the following morning it had advanced into the upper Missouri Valley, and sharp changes to colder weather had occurred over the Great Plains as far south as the Texas Panhandle. During the following 24 hours the center of highest pressure moved to the lower Missouri Valley and the lowest temperatures of the month prevailed from central Texas and the lower Mississippi Valley northward to the Canadian border, with indications that during the following 24 hours it would advance farther southward and the attending cold seriously threaten the great early-fruit and vegetable districts of the South, where the continued warm weather had advanced vegetation far ahead of the usual condition so early in the spring. This was not fully accomplished, however, as the center of high pressure changed its course to the northeastward.

Areas of low pressure, as in several previous months, were mainly ill-defined, and pursued irregular courses and lacked the strong features usually expected in March. Few extensive low areas entered the Pacific Coast States during the latter half of the month and none appear to have maintained their identity sufficiently to cross the western mountains as distinctive storms.

In the absence of cyclones or anticyclones of marked strength, the winds were correspondingly moderate, and high winds were infrequent over extensive areas. Along the Atlantic coast the winds were highest about the 28th, and over the central valleys winds exceeding 50 miles per hour were reported locally on the 26th and 27th. On the Pacific coast winds were comparatively light, only a few exposed points reporting as much as 50 miles per hour.

Over practically all the country east of the Rocky Mountains southerly winds predominated, extending to the extreme northern portions of New England and into the region of the Great Lakes and portions of the upper Mississippi Valley. They were likewise southerly over many portions of the far western districts, extending northward to the Canadian boundary.

TEMPERATURE.

Over the greater part of the central and eastern districts, in fact from the Rocky Mountains eastward, March, 1921, temperatures partook more nearly of those expected in April than those usually existing in the first spring month. Temperatures were also more uniform than usual, few abrupt changes occurring until near the close, when unusually high temperatures for March were quickly followed by the lowest temperatures of the month, due to the rapid advance of a severe cold wave for the season into the central and northeastern districts from the 27th to 29th.

For the month as a whole, the temperature averages were above normal in all parts of the country, but more particularly in the central and eastern districts, where the average excess ranged from 6 to 12° per day, and the monthly averages were in many cases the highest ever known for March, and in some cases higher than the normals for April. This excess was not the result of periods of extreme heat, but rather of daily temperatures continuously higher than normal; in some cases this excess was almost continuous save for two or three days near the end of the month.

The principal periods of maximum heat were near the end of the second and at the beginning of the third decades, when temperatures of 90° F. or slightly higher were recorded over much of the country from the Rocky Mountains eastward, and near the end of the month on the Pacific coast. The highest temperature recorded, 100° F., was reported from a point in Texas.

The principal periods of low temperature were near the first of the month over the Southeastern States, about the end of the first decade in the central and southern portions of the Great Plains and Rocky Mountains, and over the central valleys and middle eastern districts near the end of the month. The lowest temperature, $-34°$ F, occurred in Montana, and temperatures between 20° and 30° below zero were reported from several other Rocky Mountain States, and generally along the northern border from Lake Superior westward to the mountains. Minimum temperatures reached the freezing point in portions of all the Southern States except in Florida, where the lowest observed temperature was 33° F.

The cold wave near the end of the month, while not so severe as others that have occurred in March of previous years, was exceedingly destructive to early vegetation in the central districts from the southern plains northeastward, due to the great advance made on account of the long period of unusual warmth preceding. A more complete statement concerning damage to vegetation by the cold of this period will be found in another portion of this REVIEW.

PRECIPITATION.

On account of the prevailing general warmth of the month, the precipitation distribution more nearly resembled that common to the warmer months of the year, thunderstorms being frequent and wide variations occurring in the total monthly falls at near-by points.

Precipitation was frequent and comparatively heavy over the Mississippi and Ohio Valleys, and the amounts from the eastern plains to the Atlantic coast were usually sufficient for current needs, although the East Gulf and and Atlantic Coast States had considerably less than usually falls in March, the deficiency being large in Georgia and portions of adjoining States.

West of the Rocky Mountains the precipitation for the month was less than usually falls save over the more northern districts, where there was a slight excess.

SNOWFALL.

Over the districts from the Great Plains eastward, the snowfall was usually light and its distribution was confined mainly to central and northern districts. In the Rocky Mountains and portions of the adjacent plains to the eastward considerable snow occurred during the month, and smaller amounts occurred generally in the mountains from central California northward.

The outlook for water during the coming summer from the accumulated snow in the high mountains continues good in the northern districts, where irrigation water is needed, and moderately so in most central districts, but continues poor over the southern sections.

RELATIVE HUMIDITY.

In the lower Lake region and southward throughout the Appalachian Mountain district, in the Missouri Valley, and westward over the Great Plains from Kansas northward, and in the Rocky Mountain and Plateau regions, the relative humidity was, as a rule, below the seasonal average; elsewhere there was relatively more moisture in the atmosphere than is usual for March.

LOCAL STORMS.

March 9: About 2 a. m. a violent local storm, probably a tornado, developed east of Macon, Miss., and moved northeastward through Prairie Point, and probably disappeared near Reform, Ala. Its path was about one-eighth mile in width and 38 miles long. According to the Macon Beacon of March 11, 1921, the winds dislodged many granite monuments in the Odd Fellows Cemetery near Macon. Some of the blocks moved were in the shape of 3-foot cubes, or larger. Many old cedar, magnolia, and live-oak trees were twisted and broken off. The damage reported, estimated at $10,000, was 5 houses partially destroyed near Macon, 3 stores, 3 dwellings, and a number of cabins blown down at Prairie Point, and 2 dwellings badly damaged at Reform. No lives were lost and only two or three persons were slightly injured.

Between about 4 and 4.45 p. m. the same day, a local storm did great damage in a strip of territory about

one-fourth mile in width and 20 miles in length from west to east across Chester County, Pa. The towns reporting the most damage were Doe Run, Romansville, and East Downington. The route of the storm may be marked from the damaged buildings and lines reported also at Avondale, Exton, Whitford, Thorndale, and Pequea. Much damage was done in Philadelphia. Many people were severely injured.

These storms developed in a narrow belt between unusually warm, moist southerly winds on the east and cold northerly winds on the west.

March 11: A tornado crossed the northwestern part of Louisiana in the vicinity of Gayle, and the Homer Oil Fields, and caused the death of three persons, injured about 35, and destroyed property having an estimated value of about $100,000. Heavy damage was also reported at Doddsville, Sunflower County, Miss., where six houses were said to have been blown down, two persons killed, and a score injured.

March 12: In Cedar Fork and Leesville townships in the northwestern part of Wake County, near Morrisville, a tornado caused property damage estimated at $10,000, but without loss of life. The characteristic tornado cloud about 100 feet wide, was seen, and a heavy downpour followed immediately after its passage. Among the freaks of the storm may be mentioned the loss of one horn by a cow which was uninjured, and the movement of a boy 400 yards through the air without injury to him.

March 17: About 10 miles west of Newport, Ark., a tornado caused injury to a number of people and property damage estimated at $10,000.

March 20: At Plainville, Adams County, Ill., a tornado of probably small proportions caused some property damage.

March 24: A tornado north of Dayton, Ohio, caused small damage in several villages, but no lives were lost.

A tornado originated about 3.30 p. m., apparently in the eastern part of Maury County, Tenn., about 8 miles northwest of Lewisburg, and traveled northeastward across the northern part of Marshall County. It was most severe and caused the greatest damage at Rich Creek, 10 miles north of Lewisburg, where four persons were killed and one injured. In the vicinity of this place the property damage amounted to $30,000 or $40,000, including the wrecking of five dwellings, four freight cars, and a number of barns and outhouses. Between 4 and 5 o'clock a "destructive wind, rain, and hail storm" was reported in the northern part of Bedford County, doubtless a continuation of the Rich Creek tornado. It reached a point 4½ miles southeast of Murfreesboro, Rutherford County, at 4.30 p. m., having covered a distance of about 40 miles during the hour. One dwelling was destroyed and considerable other damage done in that vicinity. According to reports, a peculiarity developed in the storm at this place in the form of "two tornadoes * * * about 500 yards distant from each other at the same time and houses in between the two were not in the least injured. * * * The two tornadoes were cone shaped and were distinctly observed by a number of residents."

The storm's path was very narrow, being about 100 feet in its early stages and between 30 and 40 feet later. The cloud was said to be small, the accompanying rainfall was light, and the sun was shining on both sides of the storm's path and very near thereto. While no damage seems to have occurred in adjacent counties, there were reports of hail from several places near the point of origin of the tornado.

March 26: A tornado passed over portions of Nobles County, Minn., causing the death of two persons and much property loss.

March 28: A fairly well-developed tornado occurred in the vicinity of Somerville, Somerset County, N. J., causing considerable property damage. One child was killed in a storm in the Bay Ridge section of Brooklyn, N. Y., where a motion-picture theater overturned and much other damage occurred.

March 31: A severe local storm caused considerable damage to wires and outbuildings at Port Arthur, Tex.

A tornado which is reported to have swept across the northern section of Albany, Ga., killed two people and injured several, and caused property damage estimated at from $200,000 to $300,000. After leaving Albany the storm did not come down to earth again till about 12 miles northeast of the city, in Worth County, 3 miles southwest of Oakfield, injuring two persons and wrecking several houses and other buildings.

STORMS AND WEATHER WARNINGS. WEATHER AND CROPS.

EDWARD H. BOWIE, Supervising Forecaster.

WASHINGTON FORECAST DISTRICT.

Special forecasts were made on a number of dates. Of these, the following are mentioned: On the 2d a forecast for fair and considerably colder weather with fresh west and northwest winds was issued for Washington, D. C., on Friday, March 4, when Warren G. Harding was inaugurated President of these United States; on the 24th a special forecast was sent to Lieut. Coney at Pablo Beach, Fla., to the effect that wind and weather were favorable for a start on a trans-America flying trip. Lieut. Coney left after midnight of the 24th, encountered good flying weather, but on account of motor trouble while over northern Louisiana was forced to land and while doing so his machine hit a tree and he was fatally injured.

Storm warnings on Lake Michigan.—Advisory warnings of weather and winds interfering with navigation were issued for Lake Michigan on the 5th, 8th, 12th, 19th, 20th, 24th, 26th, 27th, and 29th of the month. The severest storm of the month occurred on the 26th and 27th, when a disturbance of great intensity moved northeastward from Iowa to Lake Superior, attended by south shifting to west gales with rain and thunderstorms.

Storm warnings on the Atlantic coast.—On the 2d small-craft warnings were displayed on the middle Atlantic and New England coasts; on the 6th southwest storm warnings were displayed at and north of Delaware Breakwater and small-craft warnings south of Delaware Breakwater to Cape Hatteras; on the 9th northwest storm warnings were displayed at and north of Delaware Breakwater; on the 17th and 19th small-craft warnings were displayed on the middle Atlantic and New England coasts; on the 20th southwest storm warnings were displayed at and north of Delaware Breakwater and these warnings were continued through the 21st; on the 24th small-craft warnings were displayed on the middle Atlantic and New England coasts and later on this date the full southwest storm warnings were ordered at and north of Delaware Breakwater; on the 28th northwest storm warnings were displayed on the middle Atlantic and New England coasts. The storms of the night of the 24th and

of the 28th–29th were the severest of the month on the middle Atlantic and New England coasts. No storms of importance occurred on the coast south of Cape Hatteras.

Storm warnings on the East Gulf of Mexico Coast.—Small-craft warnings were displayed in the Pensacola and Mobile districts on the 26th and northwest storm warnings were displayed on the coast at and between Bay St. Louis, Miss., and Cedar Keys, Fla., on the 28th. No severe storm occurred over the East Gulf during the month.

Cold-wave warnings.—Cold-wave warnings were ordered on the 3d for the extreme east portion of upper Michigan; on the 12th for the region of the Great Lakes, the Ohio Valley, and Tennessee; on the 21st for the region of the Great Lakes and the Ohio Valley; on the 26th for the Upper Lake region and the lower Ohio Valley; on the 27th for the region of the Great Lakes, the Ohio Valley, and Tennessee; and on the 28th for the Eastern and Southern States, except Florida. The cold wave of the 27th–29th was the only general cold wave of the month in the Washington forecast district, and coming after a period of abnormally warm weather it was very destructive of fruit bloom and advanced vegetation over a large part of the country east of the Mississippi River.

Frost warnings were issued on a number of days for the States in this forecast district, where vegetation was advanced sufficiently to be subject to damage.

CHICAGO FORECAST DISTRICT.

Although March was one of the warmest months of that name on record in most sections of the Chicago forecast district, warnings of cold waves or freezing temperature were issued quite frequently during the month, the latter being necessary unusually early because of the advanced stage of vegetation in the southern portions of the district, due to the unusual and almost unprecedented warmth.

Cold-wave warnings for limited sections of the district were issued on the 8th, 10th, 11th, 12th, and 15th, while on the 12th were also issued the first warnings for freezing temperature, the advices being sent to Cairo, Ill., and Springfield, Mo.; on the 20th freezing temperature was indicated for Kansas and on the 21st for Kansas, Missouri, and the southern portion of Illinois.

The first cold wave of the month to sweep the district appeared in the Canadian Northwest on the evening of March 25 and during the 26th and 27th spread eastward and southward, bringing with it unseasonable cold, especially from the Rocky Mountain region over the eastern limits of the district. However, warnings for a decided drop in temperature were issued well in advance for all sections. Moreover, on Saturday, the 26th, advices for a severe freeze by Monday morning were sent to Kansas, Missouri, and Illinois, and cold-wave warnings repeated for this area, as well as for Wisconsin and portions of Minnesota and Iowa, on the morning of the 27th. Temperatures considerably below freezing prevailed in the eastern and southern portions of the district on the morning of the 28th and early reports indicate that much damage was done to grain and fruit in Illinois, Missouri, and portions of Iowa and Kansas. Temperatures close to zero or slightly below were registered in the eastern portions of the Dakotas, Minnesota, and northern Wisconsin on the 28th.

Freezing temperature was again indicated for the southern portion of this district on the 30th and 31st, although the ensuing temperatures were not so low as those experienced during the period from March 27 to 29, inclusive.

Cattle warnings were sent to the stock interests in the northern Rocky Mountain region and western Plains States on the 10th, 11th, and 26th.—*E. H. Haines.*

NEW ORLEANS FORECAST DISTRICT.

Small-craft warnings were displayed on the 20th from Galveston to Velasco, Tex., and were justified.

Southeast storm warnings were issued for the Texas coast on the morning of the 26th and northwest warnings at night on the 27th. Northwest storm warnings were ordered displayed along the Louisiana coast on the morning of the 28th. The storm of the 26th accompanied an inland trough of low pressure and the other warnings were for the area of high pressure that followed. These warnings were verified. No general storm occurred without warnings, but a thundersquall of brief duration occurred in southern Louisiana early in the morning of the 31st and was attended by gales which caused slight damage in the vicinity of Lake Pontchartrain.

The first two decades were unusually mild and vegetation advanced sufficiently by the close of the first decade to require frost warnings, if indicated, for all portions of the district except west Texas. However, no frost worthy of mention occurred during the first 20 days, except on the 10th, when there was frost in Arkansas, the northern portion of east Texas, and extreme northern Louisiana, for which warnings were issued the preceding morning.

A cold-wave warning for the northwestern portion of the district was issued on the 11th but failed of verification, as low pressure persisted west of the Rocky Mountains and the threatening area of high pressure over the northern Rocky Mountain region moved eastward.

A forecast of freezing temperature for northwestern Oklahoma and the Texas Panhandle, issued on the 20th, was fully verified; but the forecast of freezing issued on the 21st, for Oklahoma and northern Arkansas, was verified in part of Oklahoma only. "Possibly frost, if the weather clears," was forecast on the 22d for the northeastern portion of the district; but cloudy weather continued and prevented the formation of frost.

Cold-wave and live-stock warnings were issued on the 26th for northern and western Oklahoma and the Texas Panhandle and were verified. Warnings preceding the further progress of this cold spell, which was extensive, were issued on the 27th and 28th, freezing or lower being forecast on the 27th for the northern sections, except southern Arkansas, and frost and freezing on the 28th for the greater portion of the district. These warnings were verified, except that in east Texas the frost on the 29th did not reach the coast.

Warnings were issued on the 30th for freezing in northern and western Oklahoma and the Texas Panhandle and on the 31st for frost in Arkansas, interior Louisiana, and the northeastern portion of east Texas. These warnings were fully verified.

Fire-weather warnings were sent to the forest supervisors in Oklahoma on the 10th and in Oklahoma and Arkansas on the 26th, and conditions occurred generally as forecast.—*R. A. Dyke.*

DENVER FORECAST DISTRICT.

The month as a whole was considerably warmer and drier than the normal, with LOWS generally advancing from the north Pacific coast. A notable exception was

a storm which began to develop over Arizona on the 24th and which had moved to southeastern Colorado by the morning of the 26th.

On the morning of the 10th a warning of a moderate cold wave was issued for eastern Colorado. On account of the unusual action of the LOW which failed to advance eastward as had been expected, the warning failed of verification.

A second warning of a moderate cold wave for eastern Colorado and eastern New Mexico, with stockmen's warnings for Colorado and northeastern New Mexico, was issued on the morning of the 26th. The warning was verified in the extreme eastern portion of Colorado, and a temperature of 20° occurred as far westward as Denver. The southward movement of the cold wave was retarded almost 24 hours, the final minimum temperature of 24° at Roswell occurring on the morning of the 28th.

Forecasts of probable minimum temperatures on the following morning were begun at El Paso, Tex., on the 1st, and owing to the advanced stage of fruit buds, at Roswell, N. Mex., on the 13th.

Warnings of freezing temperatures were issued for extreme southeastern New Mexico on the 8th and 9th, and of freezing temperatures or frosts in the fruit valleys of Colorado or southeastern New Mexico daily, beginning with the 19th. All of these predictions were verified by the occurrence of frost, or temperatures favorable for frost formation, except in southeastern New Mexico on the 24th and 25th. No frosts or freezing temperatures occurred in sections for which warnings were required that were not forecast.

On the morning of the 26th, after the receipt of a cold-wave warning from the district center, cautionary advices were issued by the official in charge, Roswell, N. Mex., stating that the probable minimum temperature during the night in that fruit district would be 30° to 34°. During the forenoon of the 27th, and before the receipt of the State forecast which contained a warning of a temperature near freezing at Roswell, and which had been delayed on account of the failure of the Roswell observation to arrive at the regular time, the same official issued advices warning against minimum temperatures on the morning of the 28th of 26° to 28° in the Pecos Valley fruit district, and of 23° to 25° in the improbable event of clearing weather during the evening. Warnings of temperatures of 25° to 27° were distributed by him to his substations at 8.40 p. m., when clearing weather became certain. The lowest temperatures in the Roswell fruit district on the morning of the 28th were from 22° to 24°. On the morning of the 28th, warnings of temperatures of 24° to 26° were issued to all orchardists in his fruit district by the official at Roswell. The actual minimum temperature at all reporting stations on the morning of the 29th was 26°.—*J. M. Sherier.*

SAN FRANCISCO DISTRICT.

There were no severe storms during the month. Conditions, however, became sufficiently threatening to warrant the ordering of storm warnings on 10 occasions for some one or more portions of the district, and small-craft warnings twice along the north and once along the south coast. Three storm warnings were only displayed for a few hours before being ordered down.

Frost warnings were issued for one or more localities on 13 days and they were practically all verified, although the frosts that formed were not heavy enough to do any great amount of harm.

During the first week of the month both the HIGHS and the LOWS moved east with unusual rapidity. On the 8th a large high-pressure area appeared over northern Alaska. It moved very slowly southeastward to the Canadian Northwest, and in doing so forced low-pressure areas entering the North Pacific coast southward. These low-pressure areas caused the heaviest rains of the month in California on the 12th and 13th, which was about four days after the high-pressure area first appeared over northern Alaska.

From the 14th to the end of the month there was a preponderance of high-pressure areas appearing over the Canadian Northwest or the North Pacific coast. Offshoots from these at sea frequently moved inland and joined forces with those moving southeastward from Alaska, with the result that only a few LOWS could be identified as having entered the United States from the Pacific Ocean. There were a few that apparently formed over the land between the two high areas, but they were poorly supplied with moisture and in consequence there was a general deficiency in rainfall in this district during the month.—*E. A. Beals.*

RIVERS AND FLOODS.

Floods during March, 1921.

ALFRED J. HENRY, Meteorologist.

[Weather Bureau, Washington, D. C., Apr. 30, 1921.]

The month was one of unusually high temperature, but fortunately for the flood situation, the accumulated snowfall of the winter was small in all parts of the country.

Precipitation was more or less frequent, but not heavy or long continued, save in a single instance, viz, over southwestern Mississippi and southeastern Louisiana, where the rainfall was remarkably heavy between the 9th and 14th. In Pike and Walthall Counties, Miss., a total of about 17 inches fell between these dates. The rainfall in other parts of the West Pearl River basin was much smaller, but nevertheless a stage of 18.6 feet, the highest of authentic record, was registered at Pearl River gaging station. Substantial money loss to highways, bridges, and railroads was sustained in the region above named.

Flood stages in the rivers of the upper and middle Mississippi drainage were rather frequent, particularly in three periods, viz, 9th–10th, 15th–16th, and 28th–31st. The floods of the last-named period were quite general throughout Ohio and Indiana, but not severe on any stream. Owing to the time of year, agricultural interests suffered but small loss.

It now seems that a severe spring flood in either the Ohio or the lower Mississippi is not probable.

The usual tables follow:

Estimated property loss from flood, March, 1921.

River district.	Tangible property, bridges, highways, etc.	Crops. Gathered.	Crops. Prospective.	Live stock and other farm property.	Suspension of business.	Value of warnings.
Meridian, Miss.	$265,625		$41,750	$16,000	$35,460	$14,500
Little Rock, Ark.	2,000					
Fort Smith, Ark.			12,000			2,000
Indianapolis, Ind.	500		10,000			
Terre Haute, Ind.	1,200	$1,000	10,000		2,500	25,000
Cairo, Ill.						25,000

Floods during month of March, 1921.

River and station.	Flood stage.	Above flood stages—dates.		Crest.	
		From—	To—	Stage.	Date.
ATLANTIC DRAINAGE.					
Connecticut:	*Feet.*			*Feet.*	
White River Junction, Vt	13	9	18	16.8	9
	13	21	(**)	16.7	22
Hartford, Conn	16	11	19	19.9	12
	16	23	29	16.8	23, 27, 28
Mohawk:					
Utica, N. Y	11	10	10	11.3	10
Sacandaga:					
Northville, N. Y	14	10	10	14.0	10
Hoosic:					
Hoosic Falls, N. Y	3	10	10	3.7	10
Cape Fear:					
Elizabethtown, N. C	22	26	27	22.9	27
Santee:					
Ferguson, S. C	12	(*)	14	13.0	1-3
	12	29	29	12.1	29
Rimini, S. C	12	27	27	12.0	27
EAST GULF DRAINAGE.					
Tombigbee:					
Demopolis, Ala	39	17	24	43.6	20
Pascagoula:					
Merrill, Miss	20	16	20	21.8	17
Leaf:					
Hattiesburg, Miss	19	13	17	20.9	15
Pearl:					
Jackson, Miss	20	13	24	24.4	17
Columbia, Miss	18	13	21	24.0	16
West Pearl:					
Pearl River, La	13	(*)	3	13.1	1, 2
	13	15	29	18.6	16
GREAT LAKES DRAINAGE.					
Maumee:					
Fort Wayne, Ind	15	13	13	15.3	13
	15	28	(**)	16.8	29
Sandusky:					
Upper Sandusky, Ohio	13	10	10	13.2	10
	13	29	29	14.2	29
St. Joseph:					
Montpelier, Ohio	10	13	13	10.2	13
	10	28	29	11.2	28
MISSISSIPPI DRAINAGE.					
Ohio:					
Henderson, Ky	33	13	15	34.0	15
Evansville, Ind	35	13	17	36.4	14, 15
Mount Vernon, Ind	35	15	16	35.2	16
Shawneetown, Ill	35	15	18	35.7	17
Muskingum:					
McConnelsville, Ohio	22	29	30	22.2	29
Tuscarawas:					
Norris Point, Ohio	8	7	11	10.1	9
	8	29	(**)	9.7	30
Coshocton, Ohio	8	7	11	10.5	10
	8	29	(**)	12.7	29
Walhonding:					
Walhonding, Ohio	8	6	7	8.9	7
	8	10	10	8.9	10
	8	28	30	12.6	29
Scioto:					
Larue, Ohio	11	10	10	12.0	10
	11	28	30	13.0	29
Prospect, Ohio	10	10	10	10.6	10
	10	29	30	11.9	30
Bellpoint, Ohio	9	28	28	10.0	28
MISSISSIPPI DRAINAGE—continued.					
Scioto—Continued.	*Feet.*			*Feet.*	
Circleville, Ohio	10	7	11	12.0	8
	10	29	(**)	15.8	29
Chillicothe, Ohio	14	8	9	14.7	9
	14	29	(**)	20.8	30
Olentangy:					
Delaware, Ohio	9	28	28	12.0	28
Stillwater:					
West Milton, Ohio	10	28	28	10.5	28
Wabash:					
Terre Haute, Ind	16	30	(**)	16.5	31
Bluffton, Ind	12	30	30	12.1	29
Lafayette, Ind	11	14	14	12.2	14
	11	28	(**)	18.7	29, 30
Vincennes, Ind	14	31	(**)	14.5	31
Mount Carmel, Ill	15	15	15	15.0	15
	15	28	(**)	18.9	31
White (West Fork):					
Decker, Ind	18	31	31	19.0	31
Anderson, Ind	12	28	29	15.0	28
Noblesville, Ind	14	29	30	15.1	29
Elliston, Ind	19	27	(**)	25.8	31
Wisconsin:					
Knowlton, Wis	12	21	22	14.8	21
Meramec:					
Steelville, Mo	12	28	28	12.6	28
Pacific, Mo	11	25	(**)	17.0	30
Valley Park, Mo	14	28	(**)	18.8	31
Bourbeuse:					
Union, Mo	10	29	30	13.6	30
Talahatchie:					
Swan Lake, Miss	25	(*)	4	25.3	1, 2
	25	16	(**)	27.5	25-29
Ouachita:					
Camden, Ark	30	15	21	35.1	17
Arkansas:					
Fort Smith, Ark	22	24	25	22.8	25
Dardanelle, Ark	20	26	26	20.6	26
Neosho:					
Fort Gibson, Okla	22	23	24	26.0	24
Petit Jean:					
Danville, Ark	20	13	16	22.0	15
White:					
Calico Rock, Ark	18	23	26	25.6	24
Batesville, Ark	23	24	(**)	31.6	25
Newport, Ark	26	26	(**)	28.8	27
Georgetown, Ark	22	28	(**)	25.2	31
Black:					
Black Rock, Ark	14	23	(**)	21.6	29
Cache:					
Patterson, Ark	9	14	16	9.2	15, 16
	9	25	(**)	9.4	29
Sulphur:					
Finley, Tex	24	16	22	25.9	17
Ringo Crossing, Tex	20	13	17	23.5	15, 16
WEST GULF DRAINAGE.					
Trinity:					
Trinidad, Tex	28	(*)	2	32.8	1
PACIFIC DRAINAGE.					
Sacramento:					
Knights Landing, Calif	18	1	2	18.4	2
Willamette:					
Portland, Oreg	15	19	20	15.1	20
Santiam:					
Jefferson, Oreg	10	17	17	10.8	17

* Continued from February.

** Continued into April.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS—MARCH, 1921.

By J. WARREN SMITH, Meteorologist.

The outstanding features of the weather during March, 1921, in its relation to agricultural and horticultural operations where the unusual and persistently mild temperatures that prevailed until near the close of the month and the disastrous cold wave that overspread nearly all sections of the country during the last few days. The unusually warm weather in all central and southern sections of the country had prematurely developed fruit to a stage of approximately one month in advance of the average season. From the 26th to the 30th a severe freeze occurred over a large section of the country where most fruit trees were in full bloom. Freezing temperatures extended as far south as the northern portions of the Gulf States and to North Carolina in the Atlantic coast section. Heavy damage to, and in most sections a complete loss of, practically all early fruit and much of the later varieties was suffered over most of the central sections of the country.[1]

The weather during the month was generally favorable for farm work and corn planting made good progress in the Southern States; cotton planting had become general over the southern portion of the belt at the close of the month. Winter grains made rapid progress until the cold wave the latter part of the month and no widespread damage occurred from the freeze. Spring-wheat seeding progressed satisfactorily for the most part, but was retarded the latter part of the month by precipitation and cold weather. By the close of the month much

[1] A more detailed account will appear in the April REVIEW.

of the crop had been sown in South Dakota and seeding was nearing completion in Iowa. The seeding of spring oats made satisfactory advance in the trans-Mississippi States but was considerably interrupted in much of the Ohio and central Mississippi Valleys by frequent rains. Truck crops in the South were favorably affected by the weather, but the freeze the latter part of the month caused much damage to early truck in Oklahoma, Arkansas, and central Texas, while some damage resulted in Tennessee and North Carolina, and locally in the northern portions of the East Gulf States. Pastures improved rapidly in the Central and Eastern States and no serious loss of stock was reported in the West.

CLIMATOLOGICAL TABLES.*

CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, March, 1921.

Section.	Temperature.								Precipitation.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	64.0	+ 7.7	Florence	89	15	2 stations	27	3†	4.90	−0.94	Citronelle	12.20	Evergreen	1.20
Arizona	55.6	+ 3.7	2 stations	98	2†	Chin Lee	8	9	0.38	−0.67	Seligman	1.98	7 stations	0.00
Arkansas	60.8	+ 8.3	Texarkana	92	21	2 stations	18	29	6.55	+2.10	Gravette	11.01	Mena	2.98
California	53.9	+ 2.1	Greenland Ranch	97	31	Fordyce Dam	8	19	2.86	−1.88	Branscomb	9.08	2 stations	0.00
Colorado	39.4	+ 4.9	Lamar	90	18	Dillon	−24	9	1.25	−0.10	Silver Lake	8.31	La Porte	0.02
Florida	70.8	+ 5.4	4 stations	94	8†	2 stations	33	1†	2.00	−1.16	Fort Lauderdale	9.90	Middleburg	0.00
Georgia	64.5	+ 7.7	Glennville	94	22	Blue Ridge	27	1	1.68	−3.21	Tallapoosa	3.80	Greensboro	0.25
Hawaii (February)	69.6	+ 1.3	2 stations	88	1†	Glenwood	46	25	2.57	−4.11	Kopiliula	7.38	Halaula	0.00
Idaho	39.3	+ 2.8	Glenns Ferry	89	28	Stanley	−10	20	1.59	−0.15	Wallace	6.84	Oakley	0.21
Illinois	50.0	+ 9.9	8 stations	83	15†	Mount Carroll	9	28	5.13	+2.10	Decatur	7.71	Griggsville	2.46
Indiana	50.5	+10.1	Marengo	88	7	3 stations	13	29	5.74	+2.01	Shelbyville	8.25	Hobart	3.17
Iowa	42.8	+ 9.5	3 stations	86	18†	Northwood	4	28	1.57	−0.20	Burlington	6.62	Waverly	0.17
Kansas	50.0	+ 7.3	Ellsworth	93	18	2 stations	6	9	1.41	+0.06	Lawrence	5.18	6 stations	T.
Kentucky	56.7	+10.7	2 stations	87	15†	Shelbyville	19	29	5.75	+1.09	Shelbyville	9.12	Pikeville	2.59
Louisiana	68.6	+ 7.8	do	92	21	Calhoun	28	29	5.75	+1.35	Clinton	15.36	Burrwood	0.59
Maryland-Delaware	53.7	+11.3	Hancock, Md	91	27	2 stations	14	29	2.39	−1.25	Denton, Md	3.71	Keedysville, Md	1.46
Michigan														
Minnesota	29.0	+ 3.6	Canby	84	18	Itasca State Park	−23	29	1.47	+0.30	Redwood Falls	2.69	Hinckley	0.34
Mississippi	65.5	+ 8.4	Anguilla	91	20	Holly Springs	27	29	7.99	+2.64	Magnolia	20.85	Bay St. Louis	2.18
Missouri	51.9	+ 8.5	Eldon	90	18	2 stations	11	28†	4.69	+1.68	Dean	11.23	Oregon	0.65
Montana	33.1	+ 2.7	Three Forks	79	3	Babb	−34	13	1.36	+0.41	Heron	5.81	Mildred	0.08
Nebraska	42.9	+ 7.3	Alma	90	18	Fort Robinson	0	7	0.64	−0.45	Fremont	2.38	4 stations	T.
Nevada	45.3	+ 4.0	Logandale	88	2†	Millett	9	27	0.40	−0.56	Sharp	2.00	3 stations	0.00
New England	39.7	+ 9.4	3 stations	84	21	2 stations	−10	5†	3.06	−0.64	Torrington, Conn	6.07	Houlton, Me	1.62
New Jersey	49.1	+10.3	Woodbine	92	27	Culvers Lake	9	30	3.03	−0.86	Dover	4.65	Somerville	1.80
New Mexico	47.7	+ 3.0	Artesia	89	17	Elizabethtown	−12	9	0.62	−0.16	Harveys Upper Ra'h	2.15	5 stations	0.00
New York	41.3	+ 9.8	4 stations	85	21	Wanakena	− 4	6	3.32	+0.30	North Lake	6.47	Chazy	0.69
North Carolina	58.6	+ 8.9	Winston-Salem	91	21	Highland	17	4	2.86	−1.50	Belhaven	6.21	Hatteras	1.18
North Dakota	25.2	+ 2.6	Ellendale	75	18	Fessenden	−22	12	1.00	+0.17	Fullerton	2.69	Taylor	0.04
Ohio	48.9	+10.1	Haydenville	87	27	Paulding	15	29	5.94	+2.47	Springfield	8.71	Gallipolis	2.73
Oklahoma	57.0	+ 4.7	Beaver	94	18	Hurley	9	9	3.12	+1.05	Claremore	7.59	2 stations	T.
Oregon	43.9	+ 1.8	The Dalles	80	29	Lapine	4	9	2.91	−0.21	Cascade Locks	11.55	Silver Lake	0.14
Pennsylvania	48.0	+10.8	Lancaster	88	28	West Bingham	7	4	3.33	−0.19	Corry	6.15	Creekside	1.05
Porto Rico	73.5	− 0.4	Cayey	92	18†	Caquas	52	19	4.67	+1.16	Comerio Falls	10.97	Potala	0.00
South Carolina	62.5	+ 7.5	3 stations	91	16†	2 stations	28	4	2.28	−1.58	Florence	4.42	Batesburg	0.77
South Dakota	37.0	+ 6.5	Howell	90	18	3 stations	− 7	21	1.08	+0.21	Castlewood	2.74	Oelrichs	0.02
Tennessee	59.6	+10.0	Newport	89	20†	Tazewell	22	4	5.43	+0.09	Moscow	11.36	Charleston	1.94
Texas	64.5	+ 5.6	Mission	100	21	Romero	10	9	2.80	+0.82	Pierce	9.59	Panhandle	0.00
Utah	42.4	+ 4.0	St. George	85	18	Black's Fork	−17	9	1.21	−0.33	Silver Lake	5.47	Myton	0.00
Virginia	55.9	+10.6	Quantico	92	21	Mount Weather	17	29	2.04	−1.71	Runnymede	4.16	Mount Weather	0.90
Washington	42.2	+ 0.8	Lowden	77	29	Republic	3	12	3.17	+0.30	Cedar Lake	9.40	2 stations	T.
West Virginia	52.7	+10.0	Charleston	90	20†	Marlinton	10	30	2.84	−0.87	Charleston	5.75	Union	0.63
Wisconsin	34.2	+ 5.6	Beloit	89	20	Winter	−19	9	2.33	+0.61	Stanley	6.10	Solon Springs	0.60
Wyoming	35.2	+ 4.3	Wyncote	82	18	Fox Park	−20	27	0.71	−0.34	Bow Ranger	2.40	Hyattville	0.00

* For description of tables and charts, see this REVIEW, January, 1921, p. 41.

† Other dates also.

TABLE I.—*Climatological data for Weather Bureau Stations, March, 1921.*

Districts and stations.	Elevation of instruments.			Pressure.			Temperature of the air.												Precipitation.			Wind.										
	Barometer above sea level.	Thermometer above ground.	Anemometer above ground.	Station, reduced to mean of 24 hours.	Sea level, reduced to mean of 24 hours.	Departure from normal.	Mean max.+mean min.÷2.	Departure from normal.	Maximum.	Date.	Mean maximum.	Minimum.	Date.	Mean minimum.	Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Total.	Departure from normal.	Days with 0.01 inch or more.	Total movement.	Prevailing direction.	Maximum velocity: Miles per hour.	Maximum velocity: Direction.	Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0–10	In.	In.
New England.							**41.4**	**+ 8.7**										**78**	**2.54**	**− 1.3**										**6.1**		
Eastport	76	67	85	30.03	30.11	+ .18	35.4	+ 6.5	65	21	42	11	19	28	28	33	29	80	3.01	− 1.3	17	9,844	s.	40	s.	31	5	12	14	6.4	5.1	0.0
Greenville, Me	1,070	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Portland, Me	103	82	117	30.02	30.14	+ .18	39.2	+ 7.2	79	21	47	14	5	31	33	35	29	72	2.61	− 1.1	15	7,822	s.	43	s.	25	10	6	15	6.0	T.	0.0
Concord	288	70	79	29.82	30.14	+ .14	41.1	+ 9.6	82	28	52	12	30	30	49	...	...	...	2.58	− 0.8	16	4,180	nw.	23	nw.	29	11	8	12	5.2	0.0	0.0
Burlington	404	11	48	29.65	30.10	+ .10	36.8	+ 9.5	71	27	46	6	4	28	42	...	...	...	2.64	+ 0.8	18	12,521	s.	62	s.	19	6	7	18	7.1	3.9	0.0
Northfield	876	12	60	29.15	30.13	+ .13	35.5	+ 9.3	72	28	46	3	4	25	51	33	29	78	2.50	− 0.2	18	7,504	s.	36	n.	28	5	7	19	7.3	4.2	0.0
Boston	125	115	188	30.00	30.14	+ .17	46.2	+11.2	83	21	56	20	5	37	36	41	37	76	1.92	− 2.2	15	8,396	sw.	37	sw.	31	10	11	10	5.5	T.	0.0
Nantucket	12	14	90	30.14	30.15	+ .17	43.4	+ 6.6	65	26	50	26	19	37	23	41	39	88	2.37	− 1.6	13	13,594	sw.	48	sw.	20	6	12	13	6.1	T.	0.0
Block Island	26	11	46	30.12	30.16	+ .18	42.4	+ 6.5	60	21	48	22	5	20	36	40	38	89	2.81	− 1.6	15	13,306	sw.	48	nw.	18	9	6	16	6.4	T.	0.0
Providence	160	215	251	29.97	30.15	+ .17	44.7	+ 9.0	84	21	54	19	19	35	39	40	35	75	2.50	− 2.1	13	10,330	s.	49	nw.	28	9	11	11	5.4	T.	0.0
Hartford	159	122	140	29.97	30.15	+ .16	45.2	+10.2	82	21	56	21	19	35	41	40	34	70	2.28	− 2.0	13	6,923	s.	37	s.	25	8	8	15	6.1	T.	0.0
New Haven	106	74	153	30.05	30.17	+ .18	45.1	+ 9.7	84	21	54	24	5	36	37	40	36	79	2.66	− 1.8	12	6,451	s.	39	nw.	21	9	14	8	5.3	T.	0.0
Middle Atlantic States.							**50.9**	**+10.6**										**75**	**2.40**	**− 1.2**										**5.4**		
Albany	97	102	115	30.03	30.14	+ .13	42.7	+10.6	78	21	53	18	4	32	44	39	34	75	2.80	+ 0.1	16	7,397	s.	34	s.	19	12	12	7	5.2	T.	0.0
Binghamton	871	10	84	29.17	30.12	+ .10	43.4	+11.4	82	27	54	12	4	32	47	...	...	...	2.79	+ 0.2	19	5,401	nw.	32	sw.	19	5	7	19	7.3	0.2	0.0
New York	314	414	454	29.81	30.16	+ .16	48.3	+10.8	80	21	57	25	29	40	44	43	37	71	2.21	− 1.9	10	14,952	s.	76	nw.	28	8	15	8	5.5	T.	0.0
Harrisburg	374	94	104	29.75	30.15	+ .12	49.6	+ 7.8	82	27	60	22	29	39	48	43	37	67	2.34	− 0.8	14	4,974	e.	27	sw.	21	9	7	15	6.0	2.0	0.0
Philadelphia	117	123	190	30.04	30.17	+ .15	52.5	+12.5	83	21	63	25	29	42	46	48	46	82	2.44	− 1.0	11	7,825	s.	36	nw.	21	8	13	10	5.7	0.1	0.0
Reading	325	81	98	29.80	30.16	......	50.1	......	84	21	62	23	29	39	53	44	38	68	2.43	− 1.1	13	4,775	se.	30	nw.	28	7	11	13	5.9	1.3	0.0
Scranton	805	111	119	29.26	30.14	+ .12	45.8	+10.9	80	27	57	19	4	35	53	41	38	76	3.17	0.0	17	5,875	sw.	34	s.	31	7	13	11	6.3	T.	0.0
Atlantic City	52	37	48	30.11	30.17	+ .15	47.8	+ 9.0	72	21	54	26	29	41	28	44	40	79	2.55	− 1.2	13	6,283	sw.	28	s.	9	10	16	5	4.7	0.0	0.0
Cape May	18	13	49	30.18	30.20	+ .19	48.3	+ 7.5	75	21	55	27	29	41	24	45	42	82	2.27	− 1.5	12	7,686	s.	36	n.	28	17	7	7	4.1	0.0	0.0
Sandy Hook	22	10	55	30.14	30.16	......	46.8	......	76	28	55	28	29	39	41	43	40	83	2.17	......	12	12,530	s.	56	nw.	28	8	15	8	5.5	T.	0.0
Trenton	190	159	183	29.94	30.15	......	50.0	......	83	21	61	24	29	39	47	45	41	76	2.42	− 1.6	13	9,582	s.	48	nw.	21	7	13	11	5.8	0.2	0.0
Baltimore	123	100	113	30.02	30.16	+ .13	54.6	+12.7	88	21	65	26	29	45	46	48	43	70	2.60	− 1.3	11	5,269	s.	25	sw.	20	12	11	8	5.4	0.0	0.0
Washington	112	62	85	30.03	30.15	+ .11	55.5	+13.3	89	21	67	26	29	44	48	48	41	65	2.76	− 1.1	10	5,742	s.	50	nw.	28	8	14	9	5.5	0.0	0.0
Lynchburg	681	153	188	29.41	30.16	+ .11	57.1	+11.7	88	21	69	25	30	45	42	50	46	73	1.75	− 2.1	8	6,508	sw.	35	n.	28	15	8	8	4.7	0.0	0.0
Norfolk	91	170	205	30.09	30.19	+ .16	58.1	+10.4	85	21	68	32	29	49	37	52	48	75	1.50	− 2.8	13	11,743	s.	50	n.	28	11	10	10	5.3	0.0	0.0
Richmond	144	11	52	30.02	30.18	+ .14	57.6	+10.7	87	21	69	28	29	46	41	52	49	82	2.13	− 1.6	10	7,801	s.	35	sw.	9	13	9	9	4.7	0.0	0.0
Wytheville	2,304	49	56	27.77	30.16	+ .12	51.8	+ 9.5	78	27	64	25	29	40	41	46	41	72	2.31	− 2.1	9	5,268	w.	30	w.	21	15	11	5	4.1	0.0	0.0
South Atlantic States.							**63.0**	**+ 9.1**										**76**	**1.78**	**− 2.5**										**5.2**		
Asheville	2,255	70	84	27.80	30.16	+ .10	55.9	+11.0	81	21	67	28	4	45	39	48	43	72	2.12	− 3.0	9	7,337	se.	32	nw.	28	13	6	12	4.9	0.0	0.0
Charlotte	779	55	62	29.32	30.16	+ .11	59.6	+ 8.8	85	21	70	35	30	49	30	53	48	72	1.84	− 2.7	10	4,727	sw.	20	sw.	21	12	5	14	5.6	0.0	0.0
Hatteras	11	12	50	30.18	30.19	+ .15	60.5	+ 9.1	78	27	68	37	5	54	24	57	54	83	1.18	− 4.3	9	12,092	sw.	49	n.	29	12	11	8	5.1	0.0	0.0
Manteo	12	5	42	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Raleigh	376	103	110	29.77	30.17	+ .12	59.2	+ 8.8	86	21	70	31	30	48	32	53	48	71	3.91	− 0.4	11	6,868	sw.	36	w.	28	10	7	14	5.6	0.0	0.0
Wilmington	78	81	91	30.11	30.20	+ .15	63.0	+ 9.3	85	16	72	38	30	54	29	57	54	80	1.44	− 2.2	8	6,697	s.	27	n.	29	13	9	9	4.6	0.0	0.0
Charleston	48	11	92	30.12	30.17	+ .06	65.1	+ 7.9	86	16	73	45	30	57	29	50	57	86	2.66	− 1.1	7	7,950	s.	38	n.	29	13	8	10	5.2	0.0	0.0
Columbia, S. C	351	41	57	29.80	30.18	+ .12	64.0	+10.0	88	16	75	38	30	53	32	56	51	72	0.97	− 2.7	8	5,654	s.	31	sw.	9	10	11	10	5.3	0.0	0.0
Due West	711	10	55	29.42	30.20	......	60.9	......	84	21	72	35	4	50	32	...	...	...	1.97	......	8	6,621	sw.	28	nw.	17	10	6	15	5.8	0.0	0.0
Greenville, S. C	1,039	113	122	29.05	30.15	......	59.0	......	82	21	69	36	4	49	30	53	49	74	2.42	......	8	6,862	sw.	33	nw.	3	12	6	13	5.5	0.0	0.0
Augusta	180	62	77	29.96	30.16	+ .10	65.5	+ 9.6	88	16	77	38	5	54	36	57	52	71	1.40	− 3.4	8	4,228	s.	24	w.	9	9	12	10	5.6	0.0	0.0
Savannah	65	150	194	30.10	30.17	+ .11	67.0	+ 8.7	87	22	76	46	4	58	27	59	56	80	1.74	− 1.9	7	9,010	s.	42	nw.	16	13	7	11	5.3	0.0	0.0
Jacksonville	43	209	245	30.11	30.16	+ .10	70.0	+ 8.1	87	16	78	50	4	62	22	62	59	80	0.57	− 3.0	2	8,744	se.	42	nw.	16	18	7	6	3.7	0.0	0.0
Florida Peninsula.							**74.3**	**+ 3.9**										**74**	**2.25**	**− 0.1**										**3.1**		
Key West	22	10	64	30.08	30.10	+ .05	76.4	+ 3.6	84	12	81	67	1	71	14	68	65	73	0.54	− 0.9	8	7,842	e.	27	e.	20	23	6	2	2.7	0.0	0.0
Miami	25	71	79	30.11	30.14	......	73.8	+ 1.8	83	17	79	56	4	69	20	67	64	73	5.15	+ 2.4	9	7,252	e.	26	e.	19	19	9	3	3.3	0.0	0.0
Sand Key	23	39	72	30.06	30.08	+ .03	74.7	......	82	17	77	68	1	73	8	69	66	73	0.47	......	9	11,037	e.	36	e.	21	20	9	2	2.9	0.0	0.0
Tampa	35	79	92	30.11	30.15	+ .08	72.6	+ 6.3	88	19	82	46	1	63	29	64	61	77	1.06	− 1.8	5	4,578	ne	22	e.	11	18	10	3	3.5	0.0	0.0
East Gulf States.							**65.6**	**+ 8.6**										**77**	**4.97**	**− 0.8**										**5.6**		
Atlanta	1,174	190	216	28.92	30.16	+ .10	61.1	+ 8.7	81	18	71	34	4	51	35	54	49	71	1.64	− 4.1	9	8,656	s.	52	w.	17	10	8	13	5.5	0.0	0.0
Leesburg	279	10	55	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Macon	370	78	87	29.76	30.16	+ .10	64.6	+ 9.8	87	22	77	35	1	53	38	56	51	69	0.86	− 4.6	7	4,579	s.	26	sw.	9	13	7	11	5.1	0.0	0.0
Thomasville	273	49	58	29.85	30.14	+ .08	68.2	+ 8.0	87	19	79	42	1	57	33	59	56	75	3.30	− 1.8	8	3,338	sw.	25	sw.	9	9	11	11	5.5	0.0	0.0
Pensacola	56	149	185	30.08	30.14	+ .08	65.8	+ 6.7	78	3	71	46	29	61	25	63	61	88	6.21	+ 0.8	6	9,538	s.	40	nw.	14	8	10	13	5.9	0.0	0.0
Anniston	741	9	57	29.36	30.15	+ .09	62.6	+10.1	84	20	74	31	1	52	38	...	...	...	3.75	− 2.0	12	4,666	s.	24	se.	12	11	13	7	4.9	0.0	0.0
Birmingham	700	11	48	29.38	30.15	+ .09	64.0	+ 8.8	84	18	75	32	29	53	34	56	51	72	4.88	− 0.9	10	6,074	s.	45	se.	12	8	14	9	5.4	0.0	0.0
Mobile	57	125	161	30.06	30.12	+ .06	66.8	+ 7.7	84	17	74	43	29	60	28	62	60	85	6.71	− 0.5	8	7,760	se.	40	nw.	14	4	18	9	6.1	0.0	0.0
Montgomery	223	100	112	29.90	30.15	+ .09	65.6	+ 7.7	85	20	76	39	29	55	33	59	54	75	5.75	− 0.6	11	5,087	s.	44	n.	16	13	9	9	5.2	0.0	0.0
Corinth	469	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Meridian	375	85	93	29.71	30.11	+ .06	66.0	− 9.7	85	20	77	35	29	55	35	58	54	74	6.53	+ 0.9	9	4,694	s.	33	se.	11	8	17	6	5.3	0.0	0.0
Vicksburg	247	65	73	29.83	30.11	+ .07	66.6	+ 8.4	85	27	76	34	29	57	32	60	57	80	9.49	+ 3.2	12	5,739	s.	34	nw.	11	5	10	16	6.6	0.0	0.0
New Orleans	53	76	84	30.05	30.11	+ .11	70.6	+ 8.6	85	17	79	47	29	62	28	64	61	82	5.59	+ 0.3	8	5,467	s.	36	nw.	31	2	19	10	6.3	0.0	0.0
West Gulf States.							**64.7**	**+ 7.4**										**78**	**4.43**	**+ 1.3**										**6.2**		
Shreveport	249	77	93	29.79	30.06	+ .04	65.7	+ 7.5	85	21	75	34	29	57	26	59	55	74	3.87	− 0.6	11	6,528	se.	37	w.	11	8	14	9	5.3	0.0	0.0
Bentonville	1,303	11	44	28.84	30.01	......	56.0	+ 8.7	85	18	67	24	29	45	38	...	...	...	9.50	+ 5.7	11	6,332	s.	30	s.	26	10	7	14	6.0	0.0	0.0
Fort Smith	457	79	94	29.53	30.01	......	60.8	+ 9.5	87	17	71	30	29	51	34	54	49	72	3.81	+ 0.2	11	7,306	e.	34	s.	5	7	8	16	6.2	0.0	0.0
Little Rock	357	136	144	29.66	30.04	+ .01	61.3	+ 8.4	85	17	70	30	29	52	40	55	50	72	7.03	+ 2.1	13	6,448	s.	39	s.	7	8	12	11	5.8	0.0	0.0
Brownsville	57	4	26	...	...	...	74.3	...	92	8	83	49	28	65	29	...	...	...	0.88	...	4	...	se.	...	...	...	...	...	...	...	0.0	0.0
Corpus Christi	20	69	77	29.98	30.00	+ .02	70.4	+ 6.0	81	27	76	46	28	65	29	66	64	86	2.25	+ 0.4	4	11,435	se.	44	n.	28	2	15	14	7.3	0.0	0.0
Dallas	512	109	117	29.46	30.01	......	63.6	......	86	16	73	32	29	54	38	...	...	...	2.75	......	8	8,313	s.	42	s.	19	6	14	11	6.0	0.0	0.0
Fort Worth	670	106	114	29.28	29.99	+ .01	63.4	+ 8.7	85	16	73	34	29	54	33	56	52	73	2.67	+ 0.9	7	9,115	s.	36	s.	20	8	9	14	6.1	0.0	0.0
Galveston	54	106	114	30.00	30.06	+ .05	68.0	+ 8.6	77	27	72	44	29	64	27	65	64	90	3.59	+ 0.7	9	9,403	se.	34	nw.	28	6	11	14	5.9	0.0	0.0
Groesbeck	461	11	56	29.53	30.01	......	64.8	......	88	27	74	34	29	53	41	...	...	...	2.64	......	7	10,567	s.	48	s.	26	3	14	14	6.9	0.0	0.0
Houston	138	111	121	29.89	30.04	......	68.7	+ 6.2	84	17	76	40	29	61	24	...	...	...	3.04	......	7	7,934	se.	38	se.	28	3	17	11	5.2	0.0	0.0
Palestine	510	64	72	29.50	30.04	+ .04	65.0	+ 6.5	84	24	74	36	29	56	40	59	55	76	3.55	+ 0.1	10	6,968	s.	35	w.	13	3	14	14	6.6	0.0	0.0
Port Arthur	34	58	66	30.01	30.05	......	68.7	......	81	22	74	40	29	63	27	64	63	87	2.42	......	6	9,298	s.	48	w.	31	4	17	10	6.4	0.0	0.0
San Antonio	701	119	132	29.27	30.00	+ .02	67.0	+ 4.9	86	24	74	41	29	58	33	60	56	76	5.91	+ 4.3	10	6,974	se.	37	n.	27	9	10	12	5.7	0.0	0.0
Taylor	582	55	63	29.43	30.04	+ .05	65.6	+ 5.9	85	25	75	35	29	57	38	...	...	...	2.13	− 0.5	10	8,216	s.	36	s.	19	4	8	19	7.4	0.0	0.0

TVBLE I.—*Climatological data for Weather Bureau Stations, March, 1921*—Continued.

Districts and stations.	Elevation of instruments. Barometer above sea level.	Elevation of instruments. Thermometer above ground.	Elevation of instruments. Anemometer above ground.	Pressure. Station, reduced to mean of 24 hours.	Pressure. Sea level, reduced to mean of 24 hours.	Pressure. Departure from normal.	Temperature of the air. Mean max.+mean min.÷2.	Temperature of the air. Departure from normal.	Temperature of the air. Maximum.	Temperature of the air. Date.	Temperature of the air. Mean maximum.	Temperature of the air. Minimum.	Temperature of the air. Date.	Temperature of the air. Mean minimum.	Temperature of the air. Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation. Total.	Precipitation. Departure from normal.	Precipitation. Days with 0.01 inch or more.	Wind. Total movement.	Wind. Prevailing direction.	Wind. Maximum velocity. Miles per hour.	Wind. Maximum velocity. Direction.	Wind. Maximum velocity. Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Ohio Valley and Tennessee.							**54.5**	**+ 1.1**										**70**	**5.44**	**+ 1.0**										**6.2**		
Chattanooga	762	189	213	29.33	30.15	+ .09	60.8	+ 8.5	84	21	71	32	29	51	36	53	47	67	3.33	− 2.9	11	6,954	se.	36	sw.	9	7	14	10	5.8	0.0	0.0
Knoxville	996	102	111	29.07	30.13	+ .07	58.7	+10.5	83	21	70	30	4	47	37	51	46	68	3.61	− 2.0	8	5,582	sw.	33	sw.	8	11	5	15	6.0	0.0	0.0
Memphis	399	76	97	29.69	30.12	+ .08	61.4	+ 9.3	83	20	70	30	29	53	36	54	49	69	7.41	+ 1.6	15	7,797	s.	46	sw.	27	11	12	8	5.0	0.0	0.0
Nashville	546	168	191	29.53	30.12	+ .07	59.0	+ 9.8	82	15	69	29	29	49	31	52	46	68	5.95	+ 0.5	14	8,782	s.	40	sw.	7	8	11	12	5.9	0.0	0.0
Lexington	989	193	230	29.04	30.11	+ .06	54.6	+11.2	80	20	65	23	29	44	32	.....	.....	.....	5.06	+ 0.3	15	12,775	sw.	60	sw.	15	9	7	15	6.3	0.0	0.0
Louisville	525	219	255	29.52	30.11	+ .07	55.6	+10.3	81	20	66	25	29	46	34	49	44	70	6.65	+ 2.3	14	12,074	s.	66	sw.	15	8	13	10	5.8	T.	0.0
Evansville	431	139	175	29.62	30.09	+ .05	55.6	+11.0	80	26	65	25	29	46	32	48	43	67	4.52	− 0.1	17	11,171	sw.	45	w.	24	6	19	6	5.6	T.	0.0
Indianapolis	822	194	230	29.17	30.07	+ .03	49.9	+10.3	78	19	61	19	29	39	36	44	39	70	7.25	+ 3.2	14	10,814	s.	46	sw.	26	3	15	13	7.1	0.1	0.0
Royal Center	736	11	55	29.25	30.06	.....	46.1	.....	77	19	58	17	29	35	32	.....	.....	.....	4.51	.....	16	9,885	s.	43	w.	24	4	5	22	7.6	T.	0.0
Terre Haute	575	96	129	29.41	30.04	.....	51.4	.....	80	19	62	22	29	40	31	46	41	74	6.47	.....	16	9,664	s.	40	sw.	19	2	18	11	6.7	0.0	0.0
Cincinnati	628	11	51	29.41	30.10	+ .05	52.4	+11.6	80	20	63	22	29	42	32	.....	.....	.....	6.60	+ 3.0	15	7,276	sw.	48	nw.	27	2	17	12	6.7	T.	0.0
Columbus	824	179	222	29.22	30.11	+ .07	49.8	+10.6	78	27	60	22	29	40	32	45	41	77	7.66	+ 4.4	17	9,739	sw.	48	sw.	8	6	13	12	6.5	T.	0.0
Dayton	899	181	216	29.09	30.06	.....	50.4	+10.0	79	20	60	22	29	40	33	45	40	73	7.41	+ 4.0	16	9,360	sw.	42	sw.	8	4	17	10	6.4	0.7	0.0
Elkins	1,947	59	67	28.07	30.14	+ .09	51.0	+11.9	84	27	65	19	29	37	51	44	39	71	2.92	− 1.2	16	4,779	s.	34	nw.	21	7	10	14	6.3	T.	T.
Parkersburg	638	77	84	29.47	30.13	+ .08	53.3	+11.0	83	27	65	26	29	42	39	46	40	66	4.49	+ 0.7	14	4,983	se.	30	nw.	16	9	12	10	5.7	T.	0.0
Pittsburgh	842	353	410	29.20	30.12	+ .08	50.7	+11.2	80	27	61	19	4	40	37	44	38	66	3.36	+ 0.4	15	9,242	sw.	36	sw.	8	5	5	21	7.2	1.4	1.4
Lower Lake Region.							**43.0**	**+ 1.0**										**75**	**3.71**	**+ 1.1**										**7.3**		
Buffalo	767	247	280	29.23	30.08	+ .06	41.6	+10.4	70	19	51	12	4	32	40	37	33	77	3.40	+ 0.8	20	13,853	sw.	64	sw.	21	5	5	21	7.4	0.7	0.0
Canton	448	10	61	29.57	30.06	.....	37.3	+ 9.6	78	27	47	2	4	28	36	.....	.....	.....	3.32	+ 0.5	19	9,940	sw.	60	sw.	19	10	15	16	6.2	3.8	0.0
Oswego	335	76	91	29.72	30.10	+ .09	40.6	+ 9.2	81	27	50	9	4	31	37	36	33	77	3.12	+ 0.3	14	9,355	s.	32	ne.	17	5	6	20	7.3	1.6	0.0
Rochester	523	86	102	29.52	30.11	+ .09	42.8	+11.5	80	27	53	12	4	33	39	37	32	69	3.61	+ 0.7	19	7,098	sw.	37	w.	21	4	5	22	7.8	1.4	0.0
Syracuse	597	97	113	29.46	30.11	+ .09	42.0	+10.6	80	27	52	7	4	32	40	.....	.....	.....	2.92	+ 0.5	19	10,712	s.	47	s.	24	6	5	20	7.2	3.1	T.
Erie	714	130	166	29.30	30.08	+ .06	44.9	+11.8	76	19	55	18	4	35	37	40	36	75	3.73	+ 1.1	18	12,158	s.	46	sw.	6	3	9	19	7.4	2.2	T.
Cleveland	762	190	201	29.25	30.09	+ .06	45.6	+11.4	75	20	55	21	4	36	35	41	36	75	4.39	+ 1.6	18	11,395	s.	44	s.	8	6	3	22	7.8	0.6	0.0
Sandusky	629	62	103	29.38	30.08	+ .05	45.6	+10.4	77	19	55	22	4	36	36	.....	.....	.....	4.07	+ 1.5	19	10,542	sw.	46	s.	8	2	10	19	7.7	1.7	0.0
Toledo	628	208	243	29.38	30.07	+ .04	44.6	+ 9.8	78	19	54	19	4	35	41	40	36	76	5.15	+ 2.9	19	12,034	sw.	48	sw.	27	6	9	16	7.2	2.0	0.0
Fort Wayne	856	113	124	29.13	30.07	.....	45.8	+ 6.9	76	19	56	17	29	35	31	41	37	75	5.09	.....	16	8,545	sw.	40	sw.	6	4	9	18	7.4	T.	0.0
Detroit	730	218	245	29.26	30.07	+ .04	42.5	+ 9.6	76	19	52	16	29	33	44	38	35	78	3.36	+ 1.0	19	8,771	sw.	47	sw.	6	4	8	19	7.4	3.8	0.0
Upper Lake Region.							**34.5**	**+ 7.0**										**80**	**3.30**	**+ 1.0**										**7.3**		
Alpena	609	13	92	29.34	30.02	− .01	33.0	+ 8.0	70	20	41	10	4	25	42	30	28	84	4.28	+ 2.2	19	10,138	nw.	46	sw.	27	5	10	16	7.0	7.9	0.0
Escanaba	612	54	60	29.34	30.02	− .02	29.5	+ 6.0	57	27	36	9	9	23	41	27	23	79	2.91	+ 1.0	13	7,577	s.	31	s.	29	6	7	18	7.0	3.9	0.0
Grand Haven	632	54	89	29.33	30.03	.00	38.4	+ 7.6	67	26	47	15	29	30	30	35	32	82	4.85	+ 2.3	17	10,499	s.	45	s.	26	4	8	19	7.4	2.2	0.0
Grand Rapids	707	70	87	29.26	30.05	+ .02	41.0	+ 8.0	75	19	51	17	29	31	35	36	32	73	4.77	+ 2.2	15	5,520	se.	23	s.	27	3	10	18	7.5	1.8	0.0
Houghton	684	62	99	29.25	30.00	− .04	26.0	+ 2.2	59	25	34	4	29	18	46	.....	.....	.....	2.82	+ 0.7	22	7,866	e.	45	w.	15	2	10	19	7.8	14.7	T.
Lansing	878	11	62	29.08	30.05	.....	40.4	+ 9.1	76	19	51	13	29	30	41	36	33	80	3.34	+ 1.1	16	6,101	sw.	28	sw.	20	5	3	23	7.6	2.1	0.0
Ludington	637	60	66	29.31	30.02	.....	35.7	.....	66	26	43	15	28	29	29	33	30	82	2.88	.....	17	9,281	s.	39	s.	27	2	12	17	7.3	4.3	0.0
Marquette	734	77	111	29.22	30.04	.00	28.4	+ 4.7	58	25	36	7	28	21	42	26	23	82	2.95	+ 0.9	22	8,289	w.	49	sw.	27	2	9	20	8.0	16.4	T.
Port Huron	638	70	120	29.35	30.05	+ .02	39.6	+10.0	71	19	48	17	29	31	38	37	36	84	3.15	+ 0.7	17	9,448	sw.	35	w.	24	6	9	16	6.7	1.2	0.0
Saginaw	611	69	77	29.34	30.05	.....	39.2	.....	75	20	49	14	4	30	40	36	32	80	2.33	− 0.3	17	7,726	nw.	34	sw.	20	6	7	18	7.3	1.0	0.0
Sault Ste. Marie	614	11	52	29.32	30.04	+ .01	26.8	+ 5.5	62	27	34	3	4	19	41	25	22	84	4.07	+ 2.2	17	7,814	se.	44	nw.	16	3	10	18	7.9	7.4	T.
Chicago	823	140	310	29.14	30.04	+ .01	45.8	+11.4	78	19	55	19	28	36	33	41	38	78	4.00	+ 1.4	19	10,490	s.	39	s.	26	6	10	15	6.4	T.	0.0
Green Bay	617	109	144	29.32	30.00	− .04	35.5	+ 8.7	76	20	43	9	28	28	43	32	27	74	2.08	− 0.3	10	8,055	s.	48	sw.	27	3	9	19	7.6	2.7	0.0
Milwaukee	681	125	139	29.26	30.02	− .01	39.7	+ 8.8	77	20	48	12	28	32	38	36	31	75	2.84	+ 0.2	12	8,570	sw.	39	sw.	20	3	10	18	7.6	T.	0.0
Duluth	1,133	11	47	28.75	30.02	− .04	24.6	+ 0.5	60	19	34	− 8	28	16	40	23	20	85	1.76	+ 0.2	14	10,294	ne.	69	nw.	27	7	11	13	6.1	12.1	0.0
North Dakota.							**24.7**	**+ 3.8**										**77**	**1.13**	**+ 0.2**										**6.7**		
Moorhead	910	50	58	28.99	30.04	− .04	24.2	+ 2.8	58	18	34	− 1	28	15	37	22	19	80	1.61	+ 0.5	11	7,653	n.	40	n.	26	1	13	17	7.4	10.8	T.
Bismark	1,674	8	57	28.20	30.04	− .02	27.8	+ 5.7	66	18	40	− 6	11	16	53	24	18	70	1.00	0.0	11	7,737	nw.	38	nw.	15	4	14	13	6.5	9.9	0.0
Devils Lake	1,482	11	44	28.37	30.01	− .04	21.0	+ 2.5	56	24	32	−10	12	10	41	19	16	84	0.71	− 0.3	11	8,545	nw.	39	w.	15	4	13	14	6.9	7.5	0.0
Ellendale	1,457	10	56	28.40	30.01	.....	27.7	.....	75	18	39	− 2	12	16	50	.....	.....	.....	1.56	.....	11	11,812	nw.	58	n.	26	3	14	14	6.8	9.7	0.0
Grand Forks	835	12	89	.....	.....	.....	20.8	.....	56	18	31	− 6	12	10	36	.....	.....	.....	0.74	.....	12	.....	n.	48	nw.	15	12	10	9	.....	7.3	T.
Williston	1,878	41	48	27.95	29.99	+ .05	25.8	+ 4.2	62	3	36	− 5	11	16	42	23	18	73	1.21	+ 0.5	9	7,132	nw.	36	nw.	29	5	19	7	5.9	8.0	T.
Upper Mississippi Valley.							**45.0**	**+ 9.0**										**72**	**3.21**	**+ 0.8**										**6.2**		
Minneapolis	918	102	208	28.97	29.97	.....	33.6	.....	71	18	42	2	28	25	40	.....	.....	.....	2.21	+ 0.6	8	10,381	se.	48	nw.	27	8	10	13	6.3	1.0	0.0
St. Paul	837	236	261	29.06	30.00	− .05	33.7	+ 5.5	69	18	43	2	28	24	54	.....	.....	.....	2.51	+ 0.9	9	10,521	nw.	56	nw.	27	8	11	12	6.0	4.3	0.0
La Crosse	714	11	48	29.20	29.99	− .05	38.0	+ 7.1	76	19	47	7	28	29	51	.....	.....	.....	1.32	− 0.3	11	5,163	se.	34	sw.	27	6	12	13	6.4	1.2	0.0
Madison	974	70	78	28.96	30.03	− .01	37.4	+ 7.3	77	20	46	9	28	29	48	34	30	78	1.81	− 0.4	11	8,604	nw.	48	sw.	20	4	7	20	7.5	T.	0.0
Wausau	1,247	4	.....	28.62	29.99	.....	32.1	.....	73	19	40	2	28	24	49	.....	.....	.....	2.76	.....	10	.....	se.	.....	.....	.....	6	12	13	6.6	4.2	0.0
Charles City	1,015	10	49	28.91	30.01	− .04	38.5	+10.1	77	19	48	8	28	29	49	34	30	77	0.93	− 1.0	8	6,607	s.	35	nw.	27	7	11	13	6.0	0.3	0.0
Davenport	606	71	79	29.35	30.02	− .01	44.8	+ 9.4	78	19	56	15	28	34	46	40	36	75	4.23	+ 2.0	10	7,127	nw.	32	sw.	27	9	5	17	6.5	T.	0.0
Des Moines	861	84	97	29.07	29.99	− .05	44.2	+ 8.5	80	19	54	13	28	34	45	38	32	68	1.07	− 0.6	7	7,238	sw.	42	sw.	10	9	8	14	6.0	0.2	0.0
Dubuque	698	81	96	29.27	30.04	.00	41.2	+ 8.0	77	19	51	12	28	32	50	36	31	72	2.05	− 0.2	12	6,393	nw.	31	sw.	20	9	8	14	6.5	T.	0.0
Keokuk	614	64	78	29.35	30.03	.00	48.4	+10.5	80	19	59	15	28	38	44	42	36	68	5.13	+ 2.8	13	7,335	nw.	35	se.	26	5	10	16	6.2	T.	0.0
Cairo	35	87	93	29.68	30.07	+ .03	57.2	+10.2	82	15	66	27	29	48	36	50	45	69	4.26	+ 0.2	14	9,508	s.	42	ne.	27	6	13	12	6.2	0.0	0.0
Peoria	609	11	45	29.37	30.04	+ .01	47.3	+10.3	79	19	59	18	28	36	39	42	38	77	4.89	+ 1.9	19	6,297	s.	22	sw.	20	8	12	11	5.4	T.	0.0
Springfield, Ill	644	10	91	29.35	30.03	.00	49.6	+10.5	81	20	60	20	28	39	36	44	39	75	5.09	+ 2.0	16	7,953	s.	34	sw.	26	6	9	16	6.4	0.2	0.0
Hannibal	534	74	109	29.44	30.02	.00	50.8	+ 9.2	80	20	62	18	28	40	42	.....	.....	.....	3.35	+ 0.6	17	8,437	sw.	42	sw.	5	7	8	16	6.2	T.	0.0
St. Louis	567	265	303	29.43	30.04	+ .01	54.0	+10.5	81	20	64	22	28	44	39	46	40	65	6.14	+ 2.7	15	12,244	s.	50	s.	5	9	14	8	5.0	0.0	0.0
Missouri Valley.							**45.3**	**+ 9.2**										**66**	**2.29**	**+ 0.4**										**5.2**		
Columbia, Mo.	781	11	84	29.18	30.02	− .01	52.0	+10.6	81	18	63	19	28	41	38	.....	.....	.....	3.37	+ 0.3	15	7,720	s.	35	s.	5	7	11	13	6.0	0.5	0.0
Kansas City	963	161	181	28.97	30.02	.00	50.9	+10.1	85	18	61	18	28	41	36	44	37	64	3.60	+ 0.8	11	10,416	s.	57	sw.	26	10	11	10	5.3	0.8	0.0
St. Joseph	967	11	49	28.94	29.99	.....	48.8	.....	84	18	59	16	28	38	36	42	35	63	1.27	.....	10	8,221	s.	42	w.	5	13	8	10	5.1	T.	0.0
Springfield, Mo.	1,324	98	104	28.62	30.04	+ .02	52.8	+ 9.3	82	18	63	20	28	42	41	47	43	75	7.35	+ 3.3	14	9,657	s.	40	sw.	8	14	8	9	4.6	0.0	0.0
Iola	984	11	50	28.95	30.00	− .01	52.1	+ 9.7	87	18	64	21	28	41	39	.....	.....	.....	3.60	+ 1.2	10	7,579	s.	28	s.	19	9	10	12	5.9	T.	0.0
Topeka	987	92	107	.....	.....	.....	49.6	+ 8.7	86	18	61	18	28	38	38	.....	.....	.....	3.04	+ 0.8	9	10,043	n.	44	s.	19	11	10	10	5.1	0.2	0.0
Drexel	1,299	10	53	28.57	29.96	.....	43.1	.....	84	18	55	11	28	31	41	36	30	66	1.69	.....	3	10,664	n.	45	sw.	19	9	12	10	5.5	T.	0.0
Lincoln	1,189	11	84	28.69	29.97	− .05	45.9	+ 9.9	87	18	58	15	28	34	41	39	32	63	0.66	− 0.7	2	9,604	n.	46	nw.	26	15	6	10	4.7	T.	0.0
Omaha	1,105	115	122	28.80	30.00	− .04	45.6	+ 9.6	85	18	56	14	28	35	38	38	30	60	1.08	− 0.3	3	7,568	nw.	39	nw.	27	12	10	9	5.1	T.	0.0
Valentine	2,598	47	54	27.22	29.98	− .05	39.6	+ 7.7	80	18	53	11	21	26	46	32	25	62	0.91	− 0.3	8	8,727	sw.	46	sw.	25	10	12	9	5.0	4.6	0.0
Sioux City	1,135	94	164	28.76	30.00	− .05	41.6	+ 9.0	82	18	52	12	28	31	44	35	28	64	0.67	− 0.6	6	10,196	s.	53	nw.	26	11	10	10	5.7	0.1	0.0
Huron	1,306	59	74	28.58	30.01	− .05	35.0	+ 8.3	84	18	48	2	28	22	46	29	24	71	1.51	+ 0.5	7	8,103	se.	44	n.	26	15	11	5	3.9	5.1	T.
Pierre	1,572	70	75	28.29	29.99	− .06	38.0	+ 8.5	85	18	52	10	21	24	45	32	26	70	0.49	− 0.8	7	8,015	nw.	51	n.	26	10	5	16	6.0	1.5	0.0
Yankton	1,233	49	57	28.66	30.00	− .05	40.3	+ 9.1	79	18	52	13	27	29	41	.....	.....	.....	1.23	+ 0.1	5	7,379	nw..	40	nw.	26	11	11	9	5.3	3.5	0.0

TABLE I.—*Climatological data for Weather Bureau Stations, March, 1921*—Continued.

Districts and stations.	Elevation of instruments: Barometer above sea level.	Elevation of instruments: Thermometer above ground.	Elevation of instruments: Anemometer above ground.	Pressure: Station, reduced to mean of 24 hours.	Pressure: Sea level, reduced to mean of 24 hours.	Pressure: Departure from normal.	Temperature of the air: Mean max. + mean min. ÷ 2.	Temperature of the air: Departure from normal.	Temperature of the air: Maximum.	Temperature of the air: Date.	Temperature of the air: Mean maximum.	Temperature of the air: Minimum.	Temperature of the air: Date.	Temperature of the air: Mean minimum.	Temperature of the air: Greatest daily range.	Mean wet thermometer.	Mean temperature of the dew-point.	Mean relative humidity.	Precipitation: Total.	Precipitation: Departure from normal.	Precipitation: Days with 0.01 inch or more.	Wind: Total movement.	Wind: Prevailing direction.	Wind: Maximum velocity: Miles per hour.	Wind: Maximum velocity: Direction.	Wind: Maximum velocity: Date.	Clear days.	Partly cloudy days.	Cloudy days.	Average cloudiness, tenths.	Total snowfall.	Snow, sleet, and ice on ground at end of month.
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Northern Slope.							**35.6**	**+ 4.8**										**62**	**0.98**	**- 0.2**										**5.8**		
Billings	3,140	5	....	....	....	....	37.4	....	79	3	52	- 5	12	23	54	....	....	....	0.87	....	6	....	....	....	....	....	7	18	6	....	0.0	0.0
Havre	2,505	11	44	27.29	30.00	.00	28.6	+ 1.3	64	28	40	-15	13	18	41	26	22	79	1.89	+ 1.4	14	6,753	sw.	37	nw.	29	4	12	15	7.1	13.0	0.0
Helena	4,110	87	112	25.70	29.97	- .04	34.4	+ 3.4	68	3	45	- 5	12	24	33	28	20	60	1.24	+ 0.5	14	5,911	sw.	38	s.	1	2	11	18	7.4	20.0	0.0
Kalispell	2,973	48	56	26.84	29.95	- .04	33.3	+ 0.3	60	31	41	5	12	26	34	30	24	70	1.55	+ 0.5	13	4,767	nw.	33	ne.	9	5	12	14	6.9	10.5	0.0
Miles City	2,371	26	48	27.41	30.02	.00	37.3	+ 8.7	69	17	50	5	8	25	42	30	24	67	1.22	+ 0.5	10	5,919	n.	36	nw.	14	6	16	9	5.9	8.9	0.0
Rapid City	3,259	50	58	26.52	30.00	- .01	37.8	+ 6.2	78	3	52	9	12	24	52	31	22	56	0.16	- 0.9	3	7,972	n.	44	n.	29	8	11	12	6.1	0.5	0.0
Cheyenne	6,088	84	101	23.91	29.94	- .02	37.6	+ 4.6	71	18	50	6	27	26	35	30	20	52	0.39	- 0.6	6	11,388	w.	54	w.	24	11	13	7	4.7	4.0	T.
Lander	5,372	60	68	24.54	29.94	- .05	38.2	+ 6.9	70	3	52	12	12	24	44	30	21	55	0.69	- 0.9	4	5,291	w.	48	sw.	18	12	17	2	4.5	7.3	0.0
Sheridan	3,790	10	47	26.01	29.98	....	35.6	....	71	17	49	5	12	22	48	29	20	61	0.65	....	8	5,388	nw.	42	nw.	5	12	11	8	4.7	3.3	0.0
Yellowstone Park	6,200	11	48	23.76	29.97	- .05	30.0	+ 3.5	55	3	40	3	12	20	40	26	20	65	1.24	- 0.9	15	8,131	s.	54	s.	14	4	16	11	6.3	12.4	T.
North Platte	2,821	11	51	27.04	30.00	.00	43.4	+ 8.1	84	18	58	17	21	29	43	34	26	60	0.42	- 0.4	3	6,433	n.	35	n.	29	14	9	8	4.5	0.8	0.0
Middle Slope.							**49.4**	**+ 6.9**										**59**	**0.88**	**- 0.6**										**5.0**		
Denver	5,292	106	113	24.64	29.92	- .03	45.0	+ 6.3	77	18	58	16	9	32	41	35	23	49	0.48	- 0.5	4	6,225	s.	46	ne.	29	10	16	5	4.8	6.5	0.0
Pueblo	4,685	80	86	25.21	29.91	- .01	47.0	+ 6.4	80	17	62	11	9	32	45	36	23	46	0.20	- 0.7	3	5,955	nw.	36	nw.	23	8	14	9	5.5	0.8	0.0
Concordia	1,392	50	58	28.51	30.00	- .01	47.6	+ 6.9	87	18	60	15	28	35	46	40	31	59	0.47	- 1.0	5	8,490	s.	44	nw.	26	10	11	10	5.6	0.2	0.0
Dodge City	2,509	11	51	27.38	30.00	- .03	49.1	+ 7.4	86	19	64	15	28	35	41	30	31	60	0.01	- 0.9	1	9,863	s.	39	ne.	30	19	6	6	3.4	0.1	0.0
Wichita	1,358	139	158	28.54	29.98	- .01	51.2	+ 7.1	83	18	62	20	28	40	35	45	39	68	2.18	- 0.1	9	12,422	s.	54	sw.	4	9	15	7	5.0	0.6	0.0
Altus	1,410	5	....	....	....	....	57.8	....	89	5	71	28	28	45	36	....	....	....	1.53	....	3	....	ne.	....	....	....	15	3	13	....	T.	0.0
Broken Arrow	765	11	52	29.18	30.01	....	55.9	....	83	18	66	26	29	46	37	....	....	....	6.21	....	12	12,014	s.	65	se.	26	8	9	14	....	0.0	0.0
Muskogee	652	4	....	....	....	....	58.5	....	87	17	69	27	29	48	33	....	....	....	5.98	....	12	....	s.	....	....	....	12	8	11	....	0.0	0.0
Oklahoma	1,214	10	47	28.72	30.00	- .02	56.6	+ 7.4	82	18	67	26	28	46	35	49	45	72	1.93	- 0.4	7	12,145	s.	42	n.	27	7	13	11	5.7	0.0	0.0
Southern Slope.							**58.6**	**+ 5.4**										**56**	**1.08**	**+ 0.2**										**4.4**		
Abilene	1,738	10	52	28.18	29.98	+ .02	61.2	+ 6.3	86	25	73	30	29	49	39	52	45	65	0.98	- 0.4	6	8,687	s.	40	s.	26	10	12	9	5.2	0.0	0.0
Amarillo	3,676	10	49	26.23	29.96	+ .01	52.0	+ 7.0	85	16	67	19	28	37	42	42	33	59	0.68	0.0	5	9,679	sw.	40	sw.	26	19	9	3	3.5	5.3	0.0
Del Rio	944	64	71	28.99	29.97	+ .02	66.8	+ 5.1	87	27	77	43	29	57	36	....	....	....	1.92	+ 0.8	7	7,611	se.	44	n.	27	9	13	9	5.1	0.0	0.0
Roswell	3,566	75	85	26.33	29.94	+ .04	54.4	+ 3.1	85	17	70	25	28	39	45	42	26	44	0.74	+ 0.3	2	6,563	s.	50	ne.	20	14	15	2	3.7	0.0	0.0
Southern Plateau.							**57.1**	**+ 3.1**										**40**	**0.19**	**- 0.3**										**2.9**		
El Paso	3,762	110	133	26.16	29.90	+ .02	59.3	+ 3.4	83	17	72	32	28	46	34	43	24	30	0.04	- 0.3	1	10,138	w.	47	sw.	26	23	8	0	2.0	T.	0.0
Santa Fe	7,013	57	66	23.20	29.93	+ .04	42.6	+ 3.2	70	17	54	16	9	32	33	33	24	54	0.75	0.0	6	5,790	sw.	30	nw.	23	11	13	7	4.8	9.0	0.0
Flagstaff	6,908	10	59	23.30	29.90	+ .01	....	....	69	17	54	20	29	27	41	....	....	....	1.06	....	5	....	w.	30	sw.	18	17	10	4	....	1.6	0.0
Phoenix	1,108	76	81	28.75	29.90	- .01	64.7	+ 4.2	95	16	79	41	27	50	46	50	34	38	0.03	- 0.5	2	4,187	e.	30	w.	25	26	1	4	2.2	0.0	0.0
Yuma	141	9	54	29.78	29.93	- .01	66.4	+ 1.9	91	17	81	45	21	51	43	52	38	43	0.09	- 0.3	4	4,730	w.	30	w.	6	23	7	1	2.0	0.0	0.0
Independence	3,957	9	41	25.95	29.98	+ .04	52.4	+ 2.8	77	17	66	27	23	39	37	40	23	35	0.06	- 0.4	2	5,299	s.	34	w.	18	18	10	3	3.4	0.0	0.0
Middle Plateau.							**44.7**	**+ 3.8**										**53**	**0.55**	**- 0.7**										**5.1**		
Reno	4,532	74	81	25.45	30.00	+ .02	45.3	+ 4.3	76	2	58	21	27	32	40	36	26	50	0.13	- 1.1	4	5,949	w.	48	w.	17	14	11	6	4.3	0.1	0.0
Tonopah	6,090	12	20	24.05	29.97	....	44.6	....	68	31	55	20	19	34	34	36	26	50	0.09	- 1.3	3	7,347	se.	42	nw.	25	9	18	4	4.5	0.5	0.0
Winnemucca	4,344	18	56	25.60	30.01	.00	43.8	+ 4.2	72	3	57	19	27	31	43	36	27	58	0.66	- 0.3	5	6,011	sw.	37	nw.	18	9	8	14	6.0	0.0	0.0
Modena	5,479	10	43	24.57	29.94	- .02	42.0	+ 2.8	70	17	56	16	9	28	46	33	21	51	1.09	- 0.2	6	8,256	sw.	43	sw.	18	16	10	5	3.7	T.	0.0
Salt Lake City	4,360	163	203	25.59	29.98	.00	46.2	+ 4.8	71	3	55	28	9	37	31	38	29	55	1.03	- 1.0	7	5,938	nw.	44	nw.	13	8	8	15	6.0	1.7	0.0
Grand Junction	4,602	60	68	25.34	29.92	- .02	46.2	+ 2.7	75	18	59	23	9	34	37	37	27	52	0.28	- 0.4	9	4,521	se.	31	sw.	19	7	8	16	6.3	T.	0.0
Northern Plateau.							**43.3**	**+ 3.0**										**63**	**1.10**	**- 0.4**										**3.9**		
Baker	3,471	48	53	26.41	30.03	.00	38.9	+ 3.4	63	31	48	20	12	30	34	34	28	67	0.50	- 0.9	10	4,890	se.	25	s.	17	13	14	4	4.2	1.2	0.0
Boise	2,739	78	86	27.15	30.03	.00	45.2	+ 3.0	70	31	55	26	27	35	36	40	34	65	0.84	- 0.6	12	4,536	nw.	30	nw.	25	10	11	10	5.4	T.	0.0
Lewiston	757	40	48	29.19	30.01	- .02	46.6	+ 2.6	70	28	56	30	30	37	37	....	....	....	0.98	- 0.3	9	3,504	e.	28	w.	25	4	10	17	7.0	T.	0.0
Pocatello	4,477	60	68	25.42	29.97	- .04	41.6	+ 4.7	64	3	51	22	20	32	32	35	27	56	0.92	- 0.8	11	7,844	sw.	36	sw.	19	6	11	14	6.3	1.6	0.0
Spokane	1,929	101	110	27.92	29.99	- .02	40.2	+ 1.3	60	28	49	16	12	32	30	35	29	65	1.15	- 0.4	11	6,534	sw.	30	sw.	16	5	14	12	6.5	5.0	0.0
Walla Walla	991	57	65	28.94	30.02	.00	47.2	+ 3.2	70	28	55	28	13	39	29	41	33	60	2.24	+ 0.4	12	4,931	s.	26	w.	19	7	14	10	5.9	3.5	0.0
North Pacific Coast Region.							**45.6**	**+ 1.2**										**80**	**3.38**	**- 1.3**										**6.9**		
North Head	211	11	56	29.83	30.07	+ 0.6	44.1	- 0.8	58	30	48	33	12	40	19	42	39	84	6.41	+ 1.2	20	11,758	nw.	62	s.	15	6	11	14	6.2	T.	0.0
Port Angeles	29	8	53	30.03	30.06	....	41.7	....	53	21	48	30	11	36	20	....	....	....	0.99	- 1.2	13	4,586	s.	26	w.	18	6	7	18	6.7	1.0	0.0
Seattle	125	215	250	29.93	30.06	+ .07	44.6	+ 0.4	58	30	50	31	14	39	21	41	37	77	3.06	- 0.5	17	6,161	se.	45	sw.	10	2	8	21	7.9	0.4	0.0
Tacoma	213	113	120	29.83	30.06	+ .06	44.6	+ 0.4	63	28	52	30	5	38	27	43	40	86	4.36	+ 0.4	16	4,868	sw.	32	sw.	25	2	13	16	7.4	1.0	0.0
Tatoosh Island	86	7	57	29.93	30.03	+ .07	43.7	+ 0.8	51	23	47	32	11	40	15	41	39	83	2.88	- 5.7	17	10,524	w.	49	w.	10	8	11	12	5.9	T.	0.0
Yakima	1,071	4	....	....	....	....	45.0	....	70	31	57	26	14	33	40	....	....	....	0.25	....	4	....	nw.	....	....	....	12	9	10	....	T.	0.0
Medford	1,425	4	....	....	....	....	47.5	....	75	28	59	26	11	36	43	....	....	....	1.06	....	11	....	nw.	....	....	....	....	....	....	....	0.0	0.0
Portland, Oreg.	153	68	106	29.91	30.07	+ .05	48.0	+ 1.7	69	28	55	34	14	41	29	44	40	74	4.28	- 0.9	14	4,778	nw.	25	sw.	16	3	5	23	8.0	T.	0.0
Roseburg	510	9	57	29.54	30.09	+ .05	48.4	+ 4.6	75	28	57	31	27	40	38	44	40	76	1.71	- 2.3	15	2,200	nw.	17	w.	22	5	16	10	6.1	0.0	0.0
Middle Pacific Coast Region.							**52.6**	**+ 1.3**										**76**	**1.89**	**- 3.8**										**6.0**		
Eureka	62	73	89	30.04	30.12	+ .06	49.8	+ 1.8	63	16	54	39	20	46	19	47	45	84	3.04	- 3.9	16	5,778	n.	37	n.	26	4	4	23	7.6	0.0	0.0
Mount Tamalpais	2,375	11	18	27.59	30.08	+ .02	47.4	+ 0.3	68	2	52	34	22	42	25	....	....	....	1.99	- 3.2	11	12,150	nw.	84	nw.	25	5	6	20	7.1	0.0	0.0
Point Reyes Light	490	7	18	29.51	30.03	....	50.4	+ 0.8	66	27	54	44	11	47	19	....	....	....	1.89	....	10	14,105	nw.	97	nw.	25	6	5	20	7.0	0.0	0.0
Red Bluff	332	50	56	29.68	30.04	.00	56.0	+ 2.2	79	30	65	40	19	47	32	50	45	69	1.80	- 2.0	9	4,258	se.	33	nw.	26	16	10	5	4.4	0.0	0.0
Sacramento	69	106	117	29.99	30.06	+ .03	55.0	+ 0.8	76	30	63	40	19	47	27	51	48	79	1.45	- 1.6	8	5,306	s.	34	nw.	26	9	15	7	4.8	0.0	0.0
San Francisco	155	208	243	29.90	30.07	+ .01	54.5	+ 1.8	73	28	60	45	29	49	22	50	45	74	2.28	- 9.6	9	6,037	w.	32	n.	26	9	8	14	5.8	0.0	0.0
San Jose	141	12	110	29.93	30.08	....	54.8	+ 1.1	75	28	65	37	27	45	36	....	....	....	0.80	- 2.2	9	4,449	se.	26	s.	13	11	8	12	5.2	0.0	0.0
South Pacific Coast Region.							**57.4**	**+ 2.0**										**73**	**1.80**	**- 0.8**										**4.8**		
Fresno	327	89	98	29.69	30.05	+ .04	56.8	+ 1.9	82	2	67	39	20	46	30	51	45	69	1.05	- 0.7	6	4,881	nw.	28	nw.	18	11	14	6	4.8	0.0	0.0
Los Angeles	338	159	191	29.66	30.03	+ .01	59.4	+ 2.5	83	29	68	44	1	51	29	52	47	73	2.75	- 0.2	6	4,541	sw.	39	nw.	25	13	8	10	4.7	0.0	0.0
San Diego	87	62	70	29.93	30.02	.06	57.5	+ 1.3	74	29	64	46	20	52	25	53	49	78	1.13	- 0.6	5	5,265	nw.	24	w.	25	10	14	7	4.8	0.0	0.0
San Luis Obispo	201	32	40	29.85	30.07	+ .01	56.0	+ 2.2	82	28	66	37	21	47	38	50	44	72	2.29	- 1.7	8	3,488	nw.	20	w.	23	11	11	9	5.1	0.0	0.0
West Indies.																																
San Juan, P. R.	82	8	54	29.95	30.04	....	74.6	....	84	3	80	67	28	70	15	....	....	....	4.75	+ 1.6	28	13,822	e.	48	e.	12	5	21	5	5.3	0.0	0.0
Panama Canal.																																
Balboa Heights	118	7	97	29.74	29.86	+ .01	80.8	- 0.7	92	10	89	70	3	72	20	72	70	76	2.98	+ 2.3	6	6,224	nw.	25	nw.	9	6	25	0	4.8	0.0	0.0
Colon	36	7	97	29.84	29.87	+ .01	81.8	+ 1.0	88	10	86	72	5	77	14	74	72	77	0.98	- 0.6	8	11,835	n.	30	ne.	30	11	19	1	4.3	0.0	0.0
Alaska.																																
Juneau	80	11	49	....	....	....	30.8	....	49	2	36	9	15	26	22	27	20	69	6.53	....	17	3,600	ne.	23	ne.	11	11	4	16	5.8	5.0	0.0

TABLE II.—*Data furnished by the Canadian Meteorological Service, March, 1921.*

Stations.	Altitude above mean sea level, Jan. 1, 1919.	Pressure.			Temperature of the air.						Precipitation.		
		Station reduced to mean of 24 hours.	Sea level reduced to mean of 24 hours.	Departure from normal.	Mean max. + mean min. ÷2.	Departure from normal.	Mean maximum.	Mean minimum.	Highest.	Lowest.	Total.	Departure from normal.	Total snowfall.
	Feet.	Inches.	Inches.	Inches.	° F.	° F.	° F.	° F.	° F.	° F.	Inches.	Inches.	Inches.
St. Johns, N. F.	125												
Sydney, C. B. I.	48	30.08	30.13	+0.25	31.0	+ 4.8	40.0	22.0	55	8	3.92	−1.01	18 0
Halifax, N. S.	88												
Yarmouth, N. S.	65	30.06	30.13	+ .18	36.1	+ 5.3	42.3	29.9	57	15	3.14	−1.71	1.5
Charlottetown, P. E. I.	38	30.04	30.08	+ .18	31.6	+ 6.2	38.7	24.6	56	13	3.97	+0.76	12.2
Chatham, N. B.	28	30.06	30.09	+ .19	31.7	+ 8.7	41.0	22.3	64	5	3.07	−0.40	13.7
Father Point, Que.	20	30.01	30.04	+ .14	24.8	+ 4.5	33.2	16.4	54	− 4	3.09	+0.36	16.7
Quebec, Que.	296	29.74	30.08	+ .12	28.7	+ 7.5	36.8	20.6	53	− 1	4.50	+1.24	7.4
Montreal, Que.	187	29.86	30.08	+ .08	33.9	+10.1	41.3	25.5	68	3	3.76	−0.03	6.1
Stonecliffe, Ont.	489	29.42	30.05	+ .04	25.8	+ 6.8	40.1	11.5	64	−12	2.01	−0.05	3.3
Ottawa, Ont.	236	29.82	30.10	+ .09	32.3	+10.8	41.2	23.5	71	− 5	5.12	+2.40	10.4
Kingston, Ont.	285	29.76	30.08	+ .07	36.6	+11.0	44.0	29.2	60	4	3.42	+0.78	5.6
Toronto, Ont.	379	29.66	30.08	+ .06	38.5	+11.2	47.0	30.1	70	7	2.11	−0.53	1.0
Cochrane, Ont.	930												
White River, Ont.	1,244	28.61	29.97	− .06	16.8	+ 4.6	30.3	3.4	50	−24	1.22	−0.16	6.0
Port Stanley, Ont.	592												
Southampton, Ont.	656	29.31			36.4	+11.7	45.4	27.5	68	9	5.15	+2.50	3.0
Parry Sound, Ont.	688	29.35	30.07	+ .05	32.2	+11.1	42.0	22.5	62	− 3	7.21	+4.98	6.0
Port Arthur, Ont.	644	29.29	30.02	− .02	22.8	+ 6.0	31.9	13.8	45	− 8	2.04	+1.07	10.4
Winnipeg, Man.	760	29.16	30.02	− .07	15.8	+ 3.5	26.0	5.7	44	−16	1.09	+0.06	10.8
Minnedosa, Man.	1,690	28.12	30.02	− .04	14.7	+ 2.2	25.2	4.2	44	−21	0.74	+0.09	7.4
Le Pas, Man.	860												
Qu'Appelle, Sask.	2,115	27.65	29.97	− .07	19.4	+ 4.5	30.5	8.4	50	−16	1.26	+0.49	12.0
Medicine Hat, Alb.	2,144												
Moose Jaw, Sask.	1,759												
Swift Current, Sask.	2,392	27.34	30.04	+ .02	24.2	+ 2.2	34.6	13.7	57	−18	0.56	−0.25	5.6
Calgary, Alb.	3,428												
Banff, Alb.	4,521												
Edmonton, Alb.	2,150												
Prince Albert, Sask.	1,450	28.42	30.07	− .01	10.9	− 1.1	24.3	−2.4	45	−34	2.71	+1.94	23.5
Battleford, Sask.	1,592	28.20	30.02	− .04	14.6	+ 1.5	25.8	3.4	47	−24	0.64	+0.18	6.4
Kamloops, B. C.	1,262	28.71	30.02	+ .10	37.9	+ 1.8	46.5	29.3	64	10	0.49	−0.08	2.2
Victoria, B. C.	230												
Barkerville, B. C.	4,180												
Triangle Island, B. C.	680												
Prince Rupert, B. C.	170												
Hamilton, Bermuda	151	30.15	30.31	+ .23	65.6	+ 3.4	71.0	60.2	75	53	1.36	−3.77	0.0

SEISMOLOGY.

W. J. HUMPHREYS, Professor in Charge.

[Dated: Weather Bureau, Washington, D. C., May 3, 1921.]

TABLE 1.—*Noninstrumental earthquake reports, March, 1921.*

Day.	Approximate time, Greenwich civil.	Station.	Approximate latitude.	Approximate longitude.	Intensity Rossi-Forel.	Number of shocks.	Duration.	Sounds.	Remarks.	Observer.
		ARIZONA.								
1921.	H. m.		° ′	° ′			Sec.			
25	0 35	Yuma	32 40	114 35	4	1	5 *ca*	Rumbling	Felt by many	J. H. Gordon.
26	23 11	....do	32 40	114 35	3	1	7 *ca*	....do	Felt by several	Do.
		CALIFORNIA.								
22	15 33	Eureka	40 48	124 10	2	1	Few	None	....do	L. B. Cooper.
25	0 30	Blythe	33 40	114 45	3				....do	G. L. Van Wagner.
25	1 25	Pot Holes	32 50	114 40	4	2	3, 2	None	Felt by many	W. N. Trenchard.
27	2 10	Maricopa	35 05	119 23	4	1	10	Rumbling	....do	E. F. Foulke.
		COLORADO.								
4	6 00	Garfield	38 35	106 20	2	1	20 *ca*	Faint	Felt by several	L. N. Felton.
8	19 15	....do	38 35	106 20	4	1	10	Rumbling	Felt by many. Two additional faint shocks during succeeding hour.	Do.
9	1 25	....do	38 35	106 20	3?	1		Faint		Do.
12	7 00	....do	38 35	106 20	2	1	10 *ca*	....do	Felt by several	Do.
22	21 45	....do	38 35	106 20	3	1	5 *ca*	Loud	Felt by several; faint rumbles on 18th and 21st also.	Do.
		ILLINOIS.								
14	18 20	Salem	38 40	89 00		1	10	Rumbling	Felt by several	J. Schwartz.
14	12 *ca*	Decatur	39 50	89 00		1	10		Felt by two experienced persons.	U. Michl.
	12 *ca*	Olney	38 45	88 10	2	1	2–3	None	Felt by several	G. B. Murray.
	12 *ca*	Kanakee	41 05	87 50	2				Felt by few	J. W. Rice.
	12 10	Paris	39 40	87 40	4	2	3 *ca*	Rumbling	Felt by many	V. Twyman.
	12 15	Danville	40 07	87 40	3			None	Felt by several	Press reports.
	12 15	Hoopeston	40 30	87 45	3?	1	2 *ca*	....do	....do	C. L. Beeman.
	12 15	Tuscola	39 50	88 30	2	1	2	....do	....do	E. C. Bailey.
	12 30 *ca*	Urbana	40 07	88 15	2?				Felt by one	R. S. Smith.
		INDIANA.								
14	12 *ca*	Indianapolis	39 50	86 10	4?				Felt by several	W. D. Pratt.
	12 12	Princeton	38 25	87 35	3?	2	10	Rattling	Felt by many	A. R. Benton.
	12 12	Terre Haute	39 30	87 25	4	1	5 *ca*	Rumbling	Some felt faint shocks on 13th	O. E. Moery.
	12 15	Rockville	39 50	87 10	4	1	30	....do	Felt by several	F. T. Baker.
	12 15	Vincennes	38 42	87 30	3	1	1–2	None	Felt by many	A. B. Brouillette.
	12 15	Indianapolis	39 50	86 10	3	1	3 *ca*	....do		E. S. Cavanaugh.
	12 15	Noblesville	40 05	86 00	2?	1			Felt by several	J. Wallace.
	12 15	Veedersburg	40 10	87 15	2	2	5–10	Faint	Felt by many	L. A. Culver.
	12 15	Crawfordsville	40 07	86 50	5	1	3	....do	....do	A. W. Johnson.
31	20 03	Mount Vernon	37 55	87 55	?	1	60		....do	G. B. Grun.
		OREGON.								
4	20 00	Portland	45 30	122 40	2–3	Several		None	Felt by several	
		SOUTH DAKOTA.								
16	23 45	Sioux Falls	43 30	96 45	3–4			....do	....do	J. H. Bechtold.

TABLE 2.—*Instrumental Reports, March, 1921.*

[For significance of symbols and abbreviations, and for a description of stations and instruments, see the REVIEW for January, 1921, p. 47.]

ARIZONA. *U. S. C. & G. S. Magnetic Observatory, Tucson.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 6		e_N	7 28 13					
		eL_E	7 27 57					
		eL_N	7 28 33					
		M_E	7 28 35	15	1,600			
		M_N	7 30 02	8		400		
		C_E	7 35 ..	8				
		C_N	7 35 ..					
		F_E	8 05 ..	9				
		F_N	7 48 ..	8				
25		e_E	0 33 15					
		e_N	0 33 28					
		eL_E	0 33 51					
		eL_N	0 33 55					
		M_E	0 34 38	14	750			
		M_N	0 34 18	14		780		
		C	0 37 ..	6				
		F	0 52 ..	6				
28		eP_E	7 55 28	6			2,930	P and S seem to be well defined.
		e	7 56 28	6				
		S_E	8 00 10					
		eS_N	8 00 06					
		i_E	8 01 25					
		eL_E	8 06 08					
		eL_N	8 05 10					
		M_E	8 08 16	23	250			
		M_N	8 06 00			150		
		C_E	8 16 ..					
		C_N	8 11 ..					
		F_E	8 55 ..	12				
		F_N	8 30 ..					
28		eP_E	22 24 09					No distinct phase.
		eP_N	22 24 15					
		C_E	22 27 ..		20			
		C_N	22 28 ..			20		

CALIFORNIA. *Theosophical University, Point Loma.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 2					100	100		Tremors.
5					250	250		
6					100	100		
7					200	200		
8					100	100		
11					100	100		
22					100	150		
25					250	350		
26					100	100		
28					200	200		

COLORADO. *Sacred Heart College, Denver.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 6		P_N	19 29 ..					No P visible on EW.
		L_N	19 34 ..					Second prelim. not discernible on NS.
		L_E	19 34 ..					
		M_N	19 35 ..	10		*8,500		
		M_E	19 36 ..	10	*6,500			
		C	19 39 ..					
		F_N	19 43 ..					
		F_E	19 44 ..					
8		L_N	7 20 ..					Very small, yet quite clear.
		L_E	7 20 ..					
		F	7 21 ..					
19-20								Wavelets, thickening of penmarks.
25		L_N	24 35 ..					P not discernible.
		L_E	24 35 ..					
		M_N	24 35 30	5		*4,000		
		M_E	24 37 ..	5	*3,500			
		C	24 39 ..					
		F	24 42 ..					

*Trace amplitude.

DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 6		P	7 30 56				3,400	
		S	7 36 03					
		eL	7 40 30					
		F	8 20 ..					
24		P	14 52 49				8,700	
		S	15 02 44					
		L	15 18 34	20				
		F	15 55 ..					
25		e	0 47 24					Phases indistinguishable.
		F	1 10 *ca.*					
28		P	7 54 10				3,000	Time correction uncertain.
		S	7 58 56					
		M	8 02 10		*25,000			
		L	8 03 30					
		F	9 10 *ca.*					
30		e	15 23 27					Faint record.
		F	15 55 ..					

ILLINOIS. *U. S. Weather Bureau, Chicago.*

Date.	Character.	Phase.	Time.	Period T.	Amplitude. A_E	Amplitude. A_N	Distance.	Remarks.
1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 1		eL	7 31 30					
		L	7 35 15	18				
		F	8 10 *ca.*					
3		P	3 26 00					
		PR2?	3 31 45					
		S?	3 34 25					
		L	3 47 05	30				
		L	3 52 00	22				
		F	5 *ca.* ..					
3		P	9 01 53					
		eL	9 24 20					
		F	10 30 *ca.*					Lost in micros.
5		L	7 28 40					
		F	8 30 *ca.*					Do.
6		P	7 30 28				2,700	
		S	7 34 50					
		L	7 36 58					
		M	7 40 45		*19,000			
		F	9 50 *ca.*					
12		P	10 37 28				3,500	
		S	10 42 48					
		L?	10 46 17					
		F	11 50 *ca.*					
16		eL	12 30 ..					
		L	12 40 ..	18				
		F	13 10 *ca.*					
21		P	4 15 13				3,200	
		S	4 20 08					
		eL	4 23 00					
		L	4 31 ..	18				
		F	5 20 *ca.*					
21		P	6 50 05					
		S	6 55 ..					
		L	6 57 50					
		F	7 25 *ca.*					
23		eL	23 23 47					
24		L	0 02 ..	18				
		F	1 *ca.* ..					
24		eL	2 31 ..					
		F	3 10 *ca.*					
24		e	9 42 00					
		L	10 13 20	18				
		F	11 50 *ca.*					
24		P	14 54 ..				6,800	
		S	15 02 20					
		L	15 14 00					
		L	15 16 30	25				
		F	16 30 *ca.*					Heavy micros.

* Trace amplitude.

TABLE 2.—*Instrumental Reports, March, 1921*—Continued.

ILLINOIS. *U. S. Weather Bureau, Chicago*—Continued.

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 25		e	0 41 56					
		i	0 44 ..					Brief period—3 sec. *ca.*
		F	1 40 *ca.*					Micros.
25		e	22 14 43					
		F	22 25 ..					
28		P	7 55 19					
		S	8 01 07					L indistinguishable.
		F	11 *postea.*					Micros.
29		L	22 57 ..	18				
		F	23 30 ..					Lost in micros.
30		P	15 23 25				5,200	
		S	15 30 15					
		eL	15 41 ..	18				
		F	16 *postea.*					Heavy micros.

MARYLAND. *U. S. C. & G. S. Magnetic Observatory, Cheltenham.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 6		eP_E	7 41 15	4				Microseisms obscure beginning, phases uncertain.
		eP_N	7 41 10					
		i_N	7 41 40					
		e_E	7 43 32					
		M_E	7 44 39		40			
		M_N	7 44 05			40		
		F	7 52 ..					
25		iP	0 48 53	3				
		eL_N	0 49 30					
		M_E	0 49 18		20			
		M_N	0 49 41			50		
		F	0 56 ..					
28		eP_N	7 54 48				3,260	
		i_E	7 55 05	4				
		i_N	7 55 05	4				
		iS_E	7 59 55					
		iS_N	7 59 49	16				
		L_E	8 03 07	30				
		L_N	8 02 40	35				
		M_E	8 06 30	20	570			
		M_N	8 05 35	20		430		
		C	8 14 ..					
		F_E	8 28 ..					
		F_N	8 40 ..					

MISSOURI. *St. Louis University, St. Louis.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 6		eP_E	7 28 54				2,500	
		S	7 33 00					
		L	7 35 24					
		M_E	7 36 ..					
		M_E	7 37 24					
		M_E	7 38 42					
		M_N	7 36 ..					
		F_E	8 14 ..					
		F_N	7 58 ..					
24		eP_E?	14 53 24				8,500	P uncertain, masked by local interference.
		S_E	15 02 36					
		L_E	15 17 ..					
		L	15 21 ..					
		F	16					
25		eP_E	0 30 30					No P on NS.
		i	0 43 36					
		M_N	0 44 00					
		M_E	0 46 24					
		F	1 01 00					
28		iP_E	7 54 57				2,900	
		S_N	7 59 30					
		S_E	7 59 24					
		L	8 03 24					
		M_N	8 04 36					
		M_E	8 00 24					
		F	9 14 ..					

NEW YORK. *Fordham University, New York.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 6		P_E	7 36 48				3,200	
		L_E	7 45 44			*2,180		
24		L_N	23 50 26					
28		P_E	7 55 36				3,500	Clock correction uncertain.
		S_E	8 00 42					
		M_E	8 08 48					

* Trace amplitude.

VERMONT. *U. S. Weather Bureau, Northfield.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 6		eL	7 41 30					
		F	8 05 *ca*					
25		e	0 50 35					
		F	1 *ca* ..					
28		e	7 56 46					
		S	8 02 ..					
		L	8 06 ..	28				
		F	8 45 ..					

PORTO RICO. *U. S. C. & G. S. Magnetic Observatory, Vieques.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 26		P_E	22 45 28					
		eP_N	22 45 34					
		L_N	22 45 56					
		M_E	22 46 27		35			
		M_N	22 46 15			85		
		F_E	22 53 18					
		F_N	22 51 23					
28		iP_E	7 54 15				2,460	Preliminary phase very well defined.
		P_N	7 54 15	6				
		PR_N	7 54 52					
		iS	7 58 17					
		SR_N	7 59 17					
		eL_E	8 00 00					
		eL_N	8 00 45					
		M_E	8 02 30		250			
		M_N	8 05 29	18		3,300		
		C_E	8 09 ..	13				
		C_N	8 10 ..	13				
		F_E	8 42 ..	12				
		F_N	8 27 ..					

CANAL ZONE. *Panama Canal, Balboa Heights.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 12		P_E	10 31 23				555*ca.*	Direction unknown.
		P_N	10 31 22					
		L_E	10 32 23					
		L_N	10 32 22					
		M_E	10 33 51		*45,000			
		M_N	10 33 58			*58,000		
		F_E	10 45 00					
		F_N	10 51 18					
21		P_E	4 09 26				451	Direction unknown; light tremors from 7.45 a. to 8.02 a.
		P_N	4.09 23					
		L_E	4 09 56					
		L_N	4 11 03					
		M_E	4 10 43		*1,100			
		M_N	4 11 32			*1,000		
		F_E	4 25 00					
		F_N	4 27 00					
28		P_E	7 51 40				1,883 *ca.*	Direction unknown.
		P_N	7 51 34					
		S_E	7 53 22					
		S_N	7 53 14					
		L_E	7 54 48					
		L_N	7 54 42					
		M_E	7 56 07		*10,000			
		M_N	7 54 49			*25,200		
		F_E	8 39 00					
		F_N	8 40 00					

CANADA. *Dominion Meteorological Service, Toronto.*

1921.			*H. m. s.*	*Sec.*	*μ*	*μ*	*Km.*	
Mar. 1		L?	7 38 06					
		M	7 49 30		*200			
		F	8 03 42					
3		i	3 30 54					
		i	3 38 00					
		L	3 48 24		*300			
		L	3 56 30					
		F						Micros.
3		L	9 43 06					
		M	9 47 54		*200			
		F	10 13 48					
5		L	7 29 18					
		eL	7 31 42		*200			
		F	8 11 *ca*					

* Trace amplitude.

TABLE 2.—*Instrumental Reports, March, 1921*—Continued.

CANADA. *Dominion Meteorological Service, Toronto*—Continued.

1921.			H. m. s.	Sec.	v	v	Km.	
Mar. 6		P	7 31 36					
		S	7 36 30					
		iL	7 41 36					
		M	7 42 18		*1,500			Alaska.
		iL	7 43 36					
		L	8 00 54					
		eL	8 03 42					
		F	8 43 36					
10		e	20 44 18					
		L	21 13 42					
		L	21 39 48		*100			
		F						Micros.
12		S	10 44 12					P not recorded. Possibly N. Ecuador.
		eL	10 47 42					
		iL	10 50 30					
		M	10 52 30		*1,800			
		F	11 55 06					
16		eL	12 45 54					
		M	12 49 06					
			to					
			12 51 06		*300			
		F	13 05 ca					
21		L	4 21 24					
		eL	4 24 18					
		eL	4 33 12					
		M	4 36 24		*300			
		F	4 58 30					
21		L	6 59 12	to				
			7 08 42					
22		L	13 08 00	to				
			13 17 12					
		M	13 19 42		*300			
		F						Micros.
24		e?	10 07 42					
		e	10 17 48					
		eL	10 22 30					
		M	10 24 48		*300			
		eL	10 29 36					
		eL	10 32 24					
		F?	11 11 12					
24		S?	15 02 42	to				
			15 04 48					Early phases interfered with by local causes.
		L	15 17 36					
		eL	15 21 12					
		iL	15 25 54					
		M	15 26 54		*2,000			
		eL	15 28 06					
		F	16 23 42					
25		L	0 46 06					
		eL	0 49 18					
		M	0 52 18		*1,000			
		F	1 40 12					
28		P	7 55 42					
		eP	7 57 18					
		i	8 00 00					
		S	8 01 18					
		i	8 03 36					
		L	8 05 48					Quake reported from Nicaragua
		M	8 08 06		*5,000		3,700	
		eL	9 02 24					
		F	10 19 12					
29		eL	22 56 30					
		eL	23 02 36					
		M	23 03 12		*300			
		F?	23 18 42					
29		L?	23 22 00					
		L?	23 33 00		*100			
		F	23 41 12					
30		e?	15 18 24					
		iS?	15 23 36					
		i	15 29 24					
		eL	15 34 54					
		M	15 36 24		*200			
		eL	15 41 54					
30		eL	16 19 18					
		eL	16 22 36					
		M	16 24 36		*300			
		eL	16 42 48					
		F	17 07 24					

*Trace amplitude.

CANADA. *Dominion Meteorological Service, Victoria.*

1921.			H. m. s.	Sec.	μ	μ	Km.	
Mar. 1		L	7 17 29					
		M	7 20 56		*300			
		F	7 38 08					
3		L	3 22 35					
		M	3 40 47		*100			
		F	4 19 38					
3		L	9 20 39					
		M	9 39 50		*200			
		F	10 33 56					
5		L	7 33 02					
		M	7 45 49		*100			
6		P	7 34 05					P may be S phase.
		L	7 37 43					
		M	7 40 58		*4,500		2,170	Alaska.
		F	8 25 43					
10		L	20 48 11					
		M	20 52 37		*500			
		F	21 04 55					
12		P	10 58 48					P may be S phase.
		L	11 01 46					
		M	11 03 14		*300			
		iL	11 05 04					
		F	11 27 49					
16		M	12 24 00		*100			Watch stopped, time approximate.
21		M	4 39 29		*200			
		F	4 50 18					
22		M	12 51 30		*100			
		F	13 05 47					
23		L?	23 24 47					
		M	23 40 01		*300			
24		M	2 22 52		*100			
24		M	10 05 46		*400			
		F	10 33 47					
24		S	14 51 06					
		L	14 57 29					
		M	15 03 24		*1,300			
		F	16 32 54					
25		P	0 40 15					
		L	0 42 13					
		M	0 45 39		*2,000		1,100	Probably Alaska.
		F	0 57 57					
28		P	7 57 32					
		S	8 03 55					
		L	8 11 47					
		M	8 21 37		*5,500		4,640	Nicaragua.
		F	10 59 00					
29		M	22 48 41		*300			
30		S	15 21 15					
		L	15 31 05					
		M	15 59 07		*400			
		F	17 33 32					
		VERTICAL SEISMOGRAPH.						
6		P	7 30 30	3				
		L	7 39 00	10				
		M	7 41 30	12	*7,000			
25		M	0 45 00	15	*3,000			
28		P	7 57 46	3				
		S	8 04 44	6				
		L	8 14 46	25				
		M	8 18 46	25	*10,000		5,290	

CANADA. *Dominion Observatory, Ottawa.*

1921.			H. m. s.	Sec.	μ	μ	Km.
Mar. 3		i	3 26 11				
		eL?$_E$	3 45 24				
		L$_E$	3 55 ..	20			
		F	4 20 ..				
3		i$_E$	9 01 45				
		eL$_E$	9 23 30	40			
		L	9 35 ..	24			
		L	9 46 ..	20			
		F	10 00 ..				

* Trace amplitude.

TABLE 2.—*Instrumental Reports, March, 1921*—Continued.

CANADA. *Dominion Observatory, Ottawa*—Continued.

			H. m. s.	*Sec.*	*v*	*v*	*Km.*	
1821. Mar. 5		$e?_E$	7 06 51					
		eL_E	7 18 42					
		L_E	7 24 30					
		L	7 40 ..	20				
		F	8 10 ..					
6		O	7 24 52				3, 740	
		P_E	7 31 51					
		S	7 37 23					
		eL_E	7 41 30					
		M_N	7 44 48	10				
		M_E	7 46 18	10				Irregular periods in M.
		L	7 50 ..	6				
		$L_N1?$	9 02 ..					
		F	9					
10		eL	21 05 ..	20				
		L	21 20 ..	17				
		L	21 30 ..					
		F	21 40 ..					
12		O?	10 29 08				(4, 830)	
		$P_v?$	10 37 25					
		S	10 43 58					Micros mask NS.
		eL_E	10 50 ..	26				
		L_E	10 52 ..	22				
		L_E	10 58 ..	13				
		F	11 35 ..					
16		e	12 16 00					
		eL_E	12 35 ..	24				
		L_E	12 45 ..	18				
		F	13 00 ..					
21		i	4 20 59					
		eL_E	4 24 12					
		L_E	4 27 ..	18				
		L_E	4 34 ..	16				
		F	4 55 ..					
21		i	6 55 55					
		e	6 59 10					
		F	7 15 *ca*					
24		e_E	9 42 50					
		e_E	9 47 10					
		eL	9 53 28					
		F	.. .. ..					Merges into next disturbance.
24		e_E	10 09 56					
		eL_E?	10 23 30	18				
		L_E	10 31 ..	16				
		L_E	10 37 ..	15				
		L_E	10 44 ..	15				
		L_E	10 53 ..	15				
		F	11 10 *ca*					

CANADA. *Dominion Observatory, Ottawa*—Continued.

			H. m. s.	*Sec.*	*v*	*v*	*Km.*	
1921. Mar. 24		O	14 41 58				8, 040	
		P_V	14 53 21					
		$PR2_{NE}$	14 58 16					
		S_E	15 02 43					
		$SR1_E$	15 08 08					
		eL_{NE}	15 17 ..					
		L	15 21 ..	20				
		L	15 31 ..	18				
		L	15 34 ..	17				
		F	16 30 *ca*					
25		e_E	0 44 16					Very unusual record; no apparent preliminary phases on any component.
		i	0 49 38					
		eL_E	0 50 04	14				
		L	0 53 45					
		F	1 45 *ca*					
25		e	22 19 30	4.5				
		F	22 27 ..					
28		O	7 49 17				3, 600	
		P	7 56 05					
		S	8 01 29					
		SR2?	8 03 37	30				
		eL?	8 06 30	20				
		L	8 15 ..	18				
		L	8 20 ..	12				
		L	8 30 ..	13				
		L_E	9 00 ..	13				
		L_E	9 26 ..	22				
		L_N1	10 40 ..					
		F	11					

No earthquakes were recorded at the following stations:

ALASKA. *U. S. C. & G. S. Magnetic Observatory*, Sitka.

Reports for March, 1921, have not been received from the following stations:

ALABAMA. *Spring Hill College*, Mobile.
DISTRICT OF COLUMBIA. *Georgetown University*, Washington.
HAWAII. *U. S. C. & G. S. Magnetic Observatory*, Honolulu.
MASSACHUSETTS. *Harvard University*, Cambridge.
NEW YORK. *Canisius College*, Buffalo; *Cornell University*, Ithaca.

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Chart I. Hydrographs of Several Principal Rivers, March, 1921.

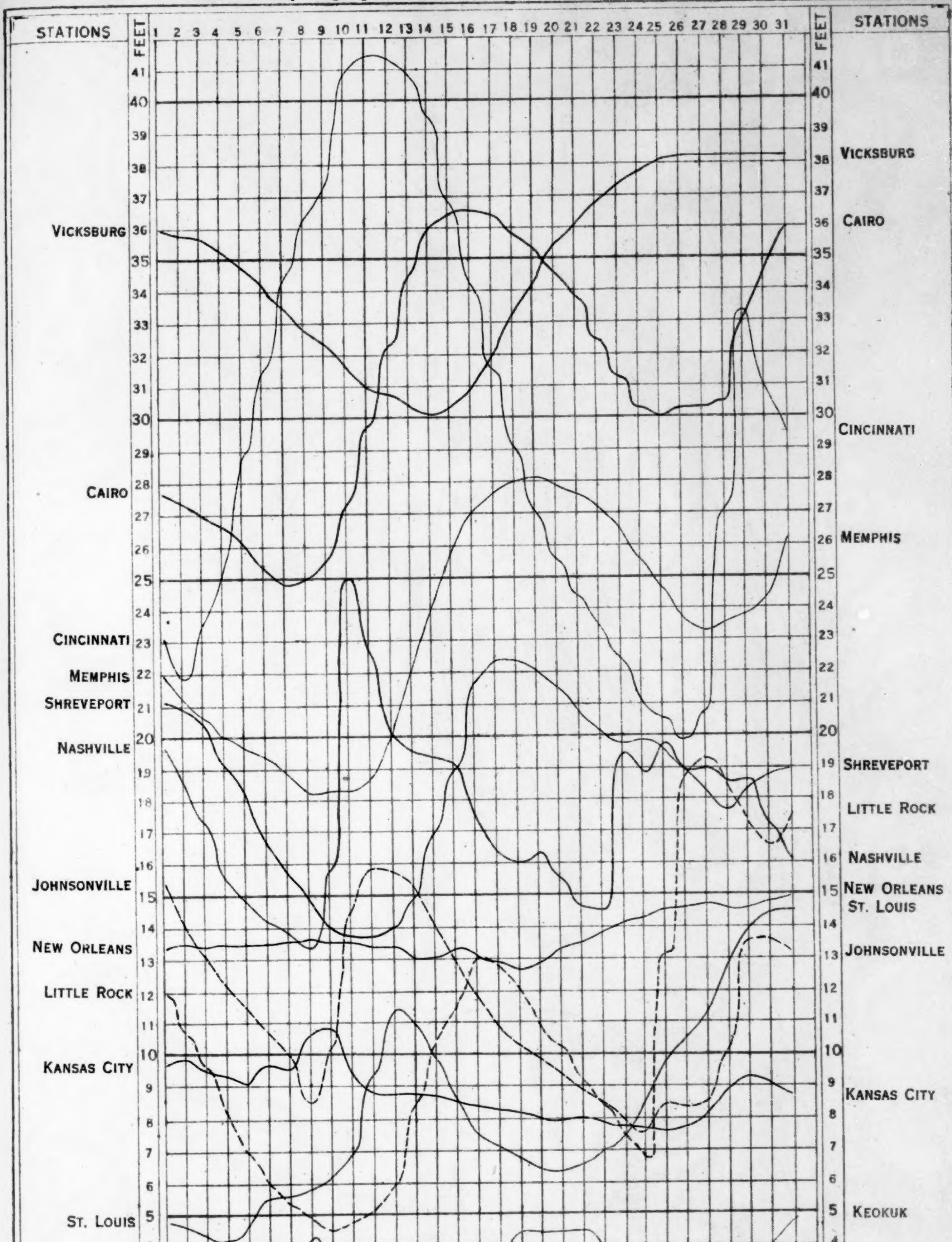


Chart II. Tracks of Centers of High Areas, March, 1921.
(Plotted by Wilfred P. Day.)

Chart III. Tracks of Centers of Low Areas, March, 1921.

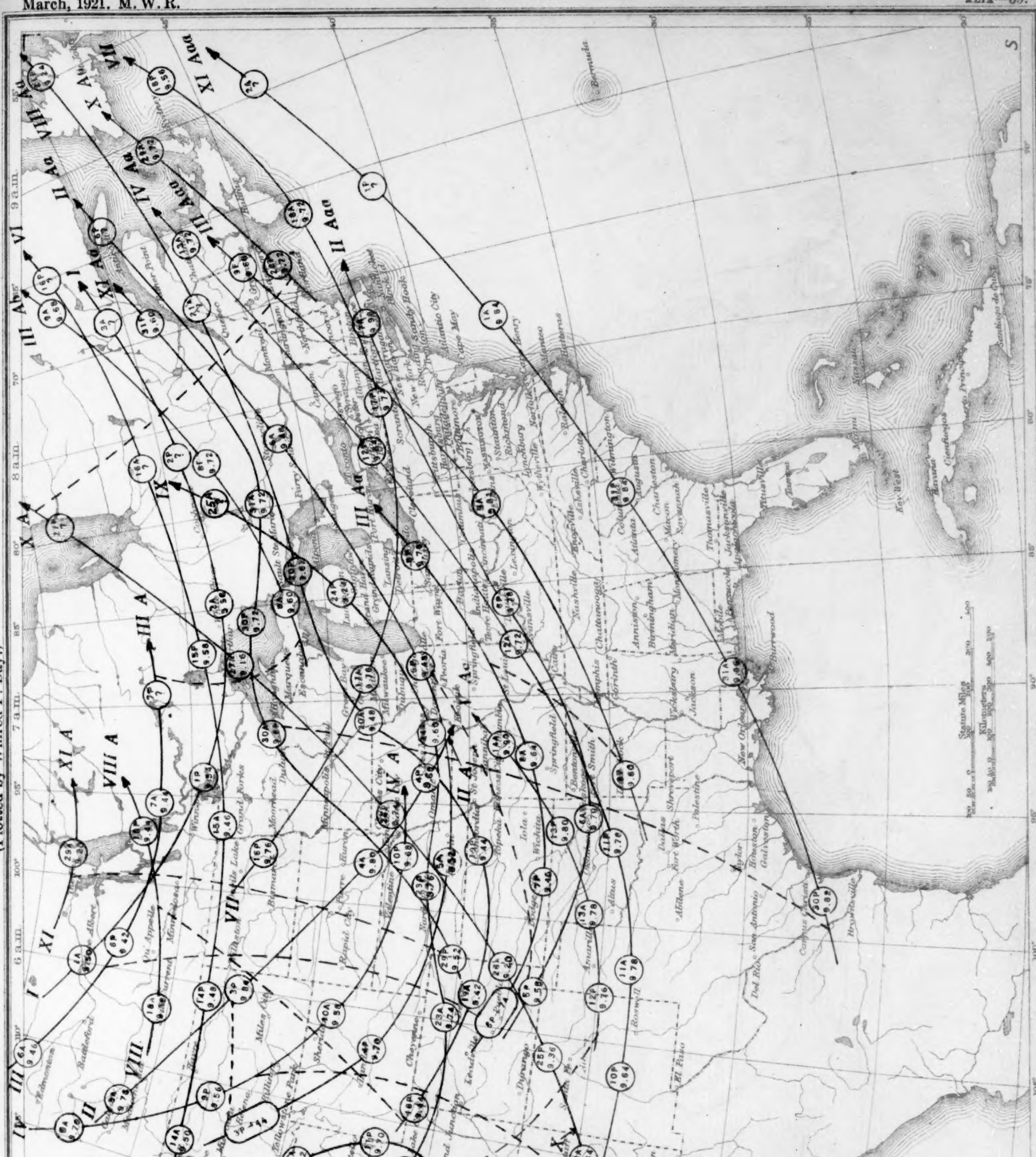


Chart III. Tracks of Centers of Low Areas, March, 1921.
(Plotted by Wilfred P. Day.)

Chart IV. Departure (°F.) of the Mean Temperature from the Normal, March, 1921.

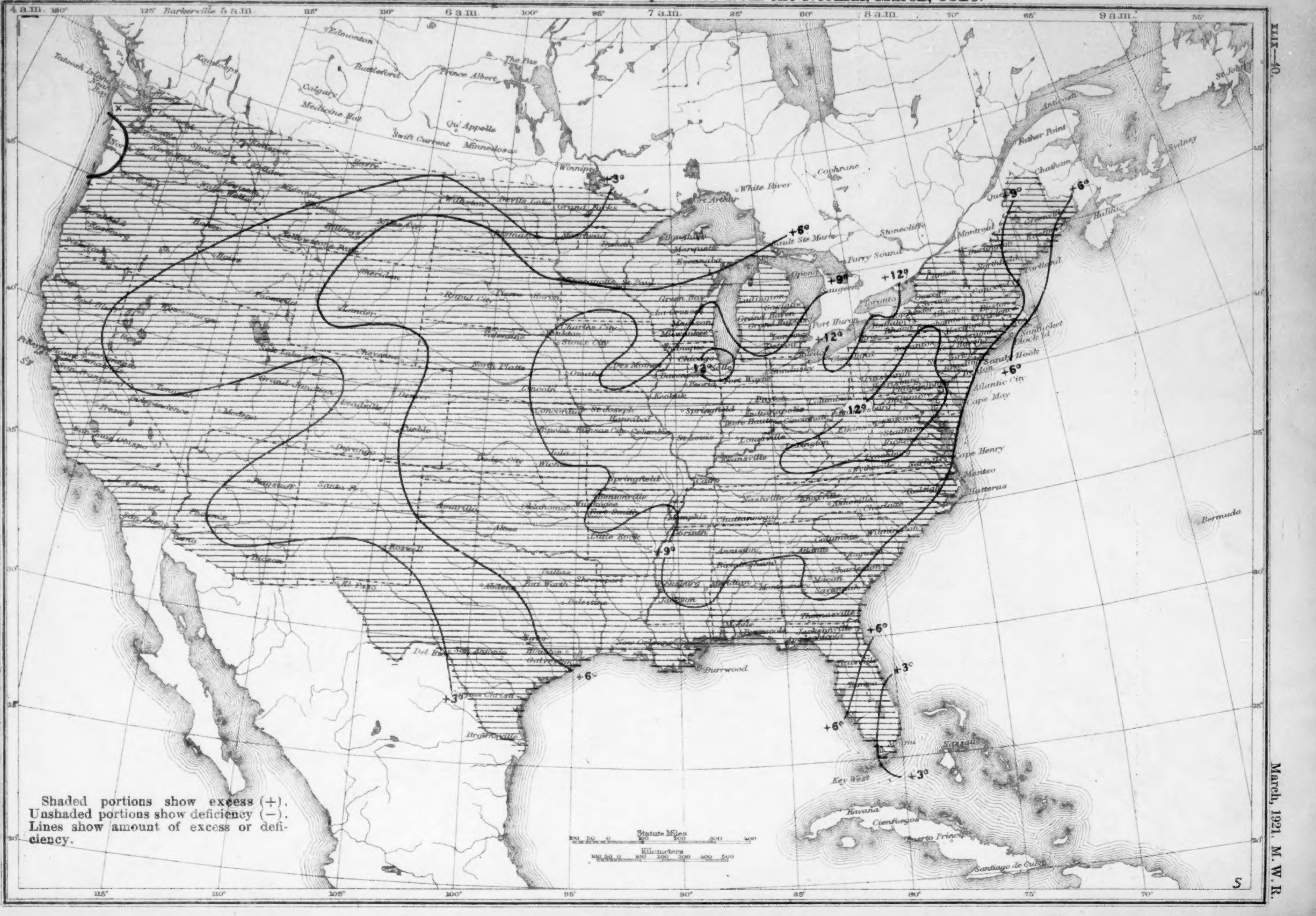


Chart V. Total Precipitation, Inches, March, 1921.

Chart VI. Percentage of Clear Sky between Sunrise and Sunset, March, 1921.

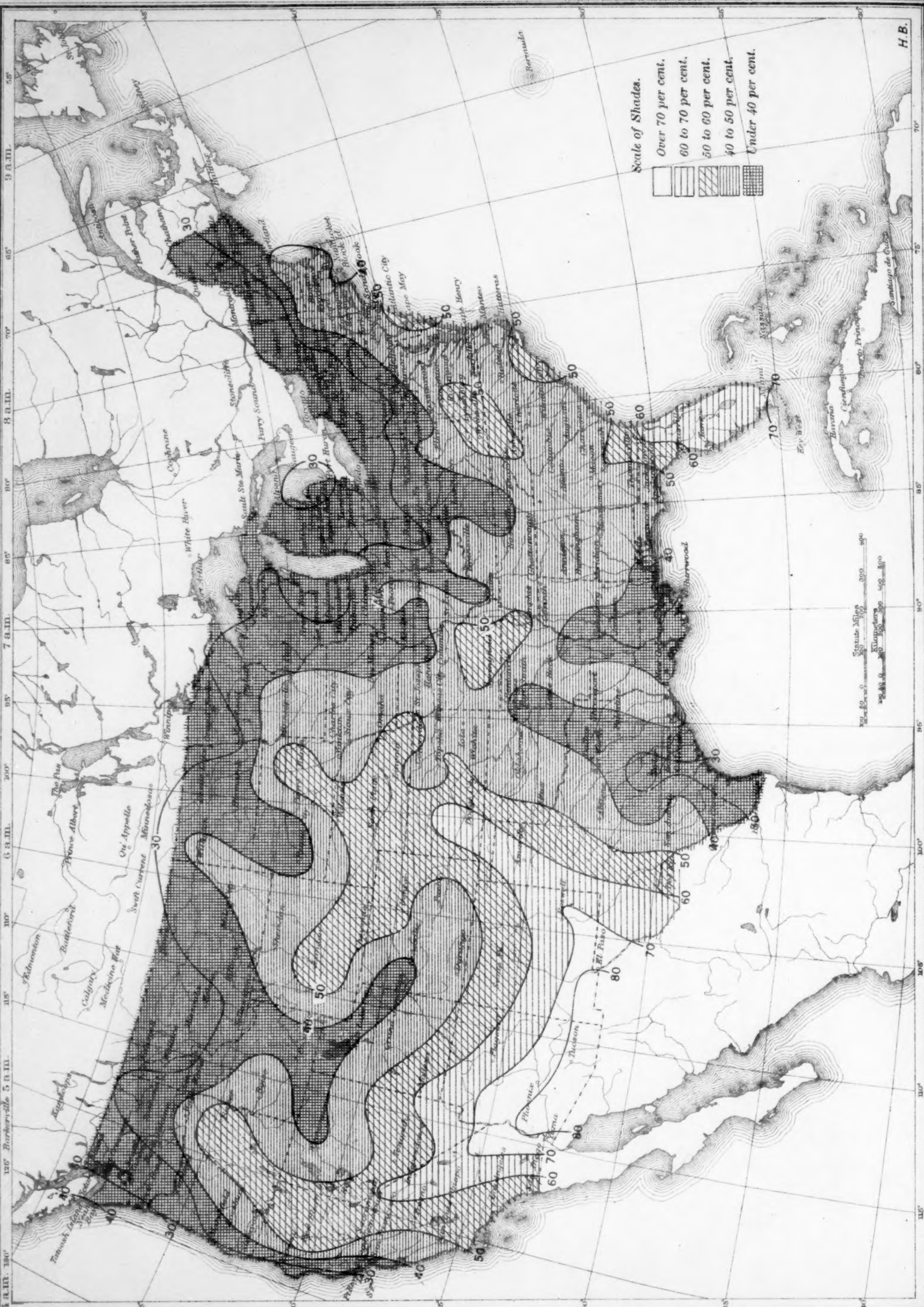


Chart VII. Isobars at Sea-level and Isotherms at Surface; Prevailing Winds, March, 1921.

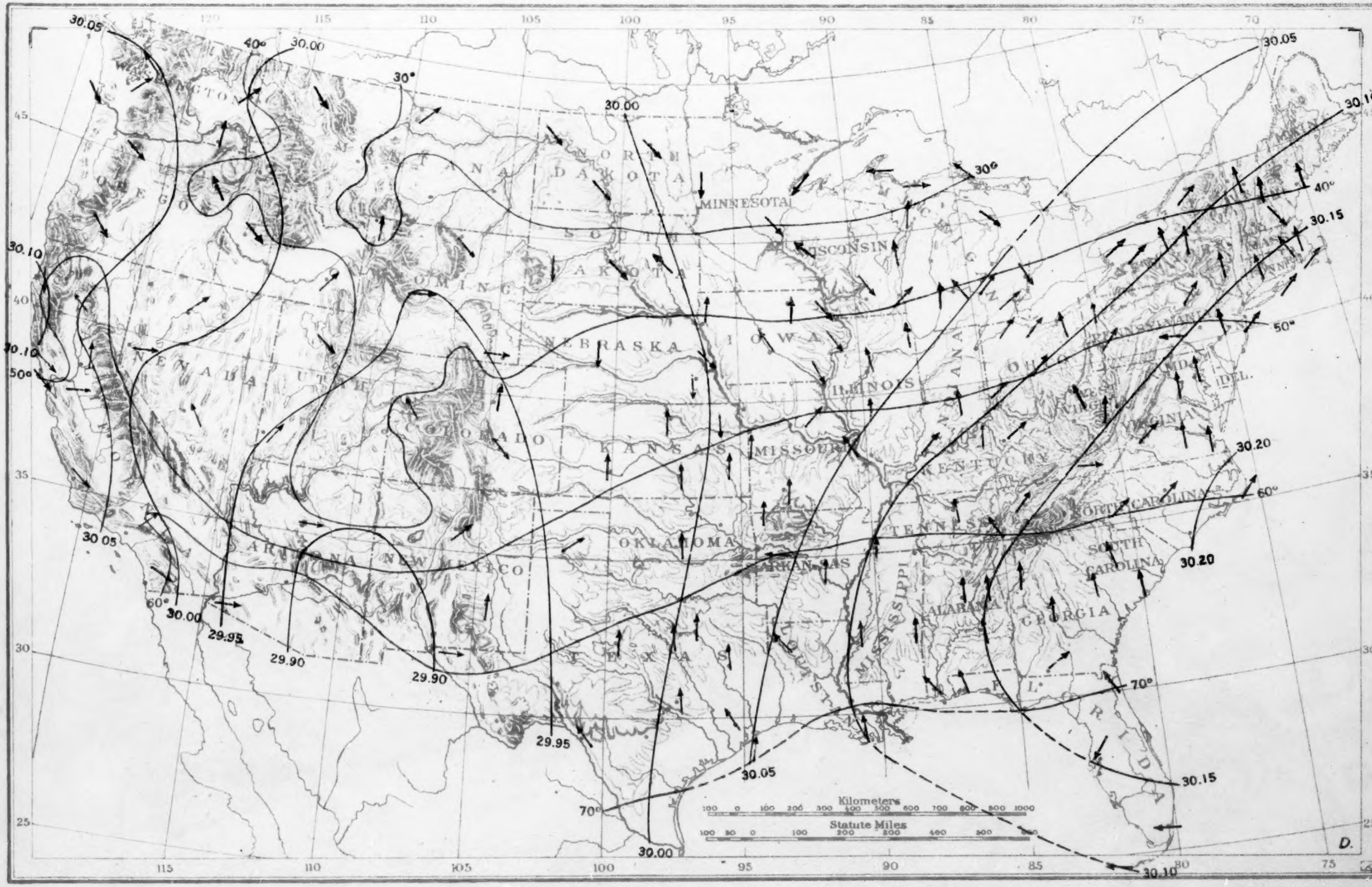


Chart VIII. Total Snowfall, Inches, March, 1921.

Chart IX. Weather Map of North Atlantic Ocean, March 12, 1921.

Chart IX. Weather Map of North Atlantic Ocean, March 12, 1921.

(Plotted by F. A. Young.)

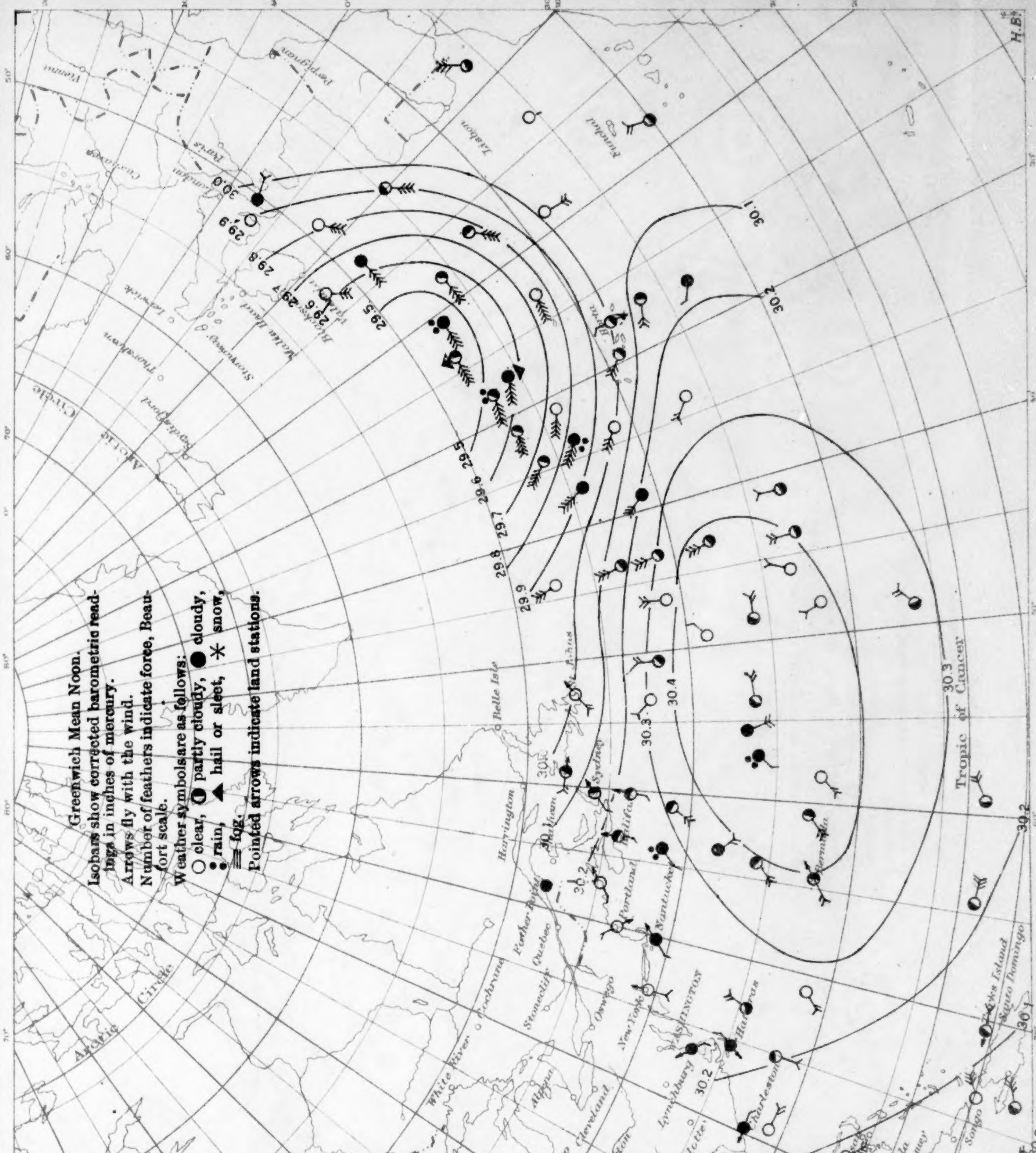


Chart X. Weather Map of North Atlantic Ocean, March 13, 1921.

(Plotted by F. A. Young.)

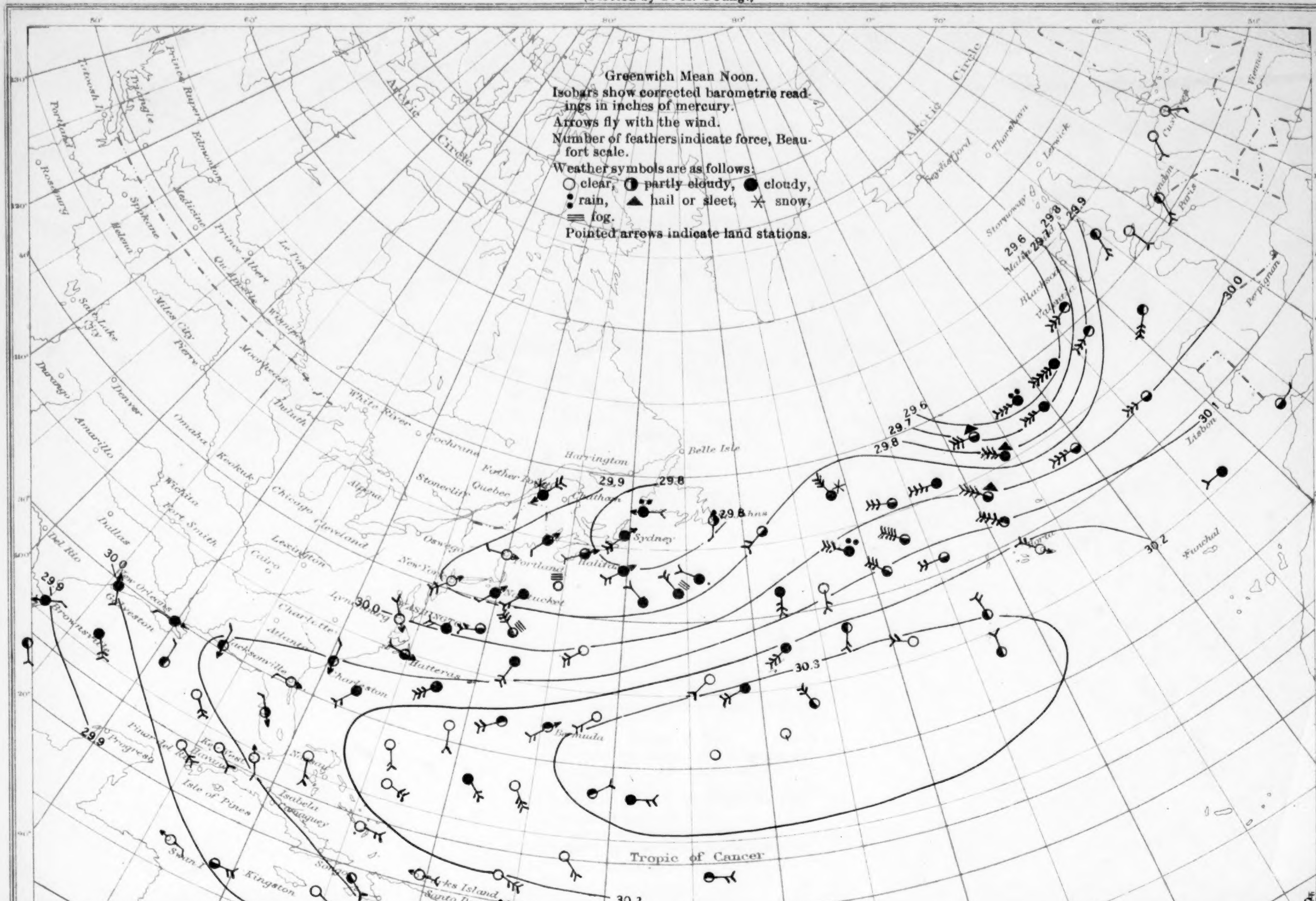


Chart XI. Weather Map of North Atlantic Ocean, March 14, 1921.

Chart XI. Weather Map of North Atlantic Ocean, March 14, 1921.

(Plotted by F. A. Young.)

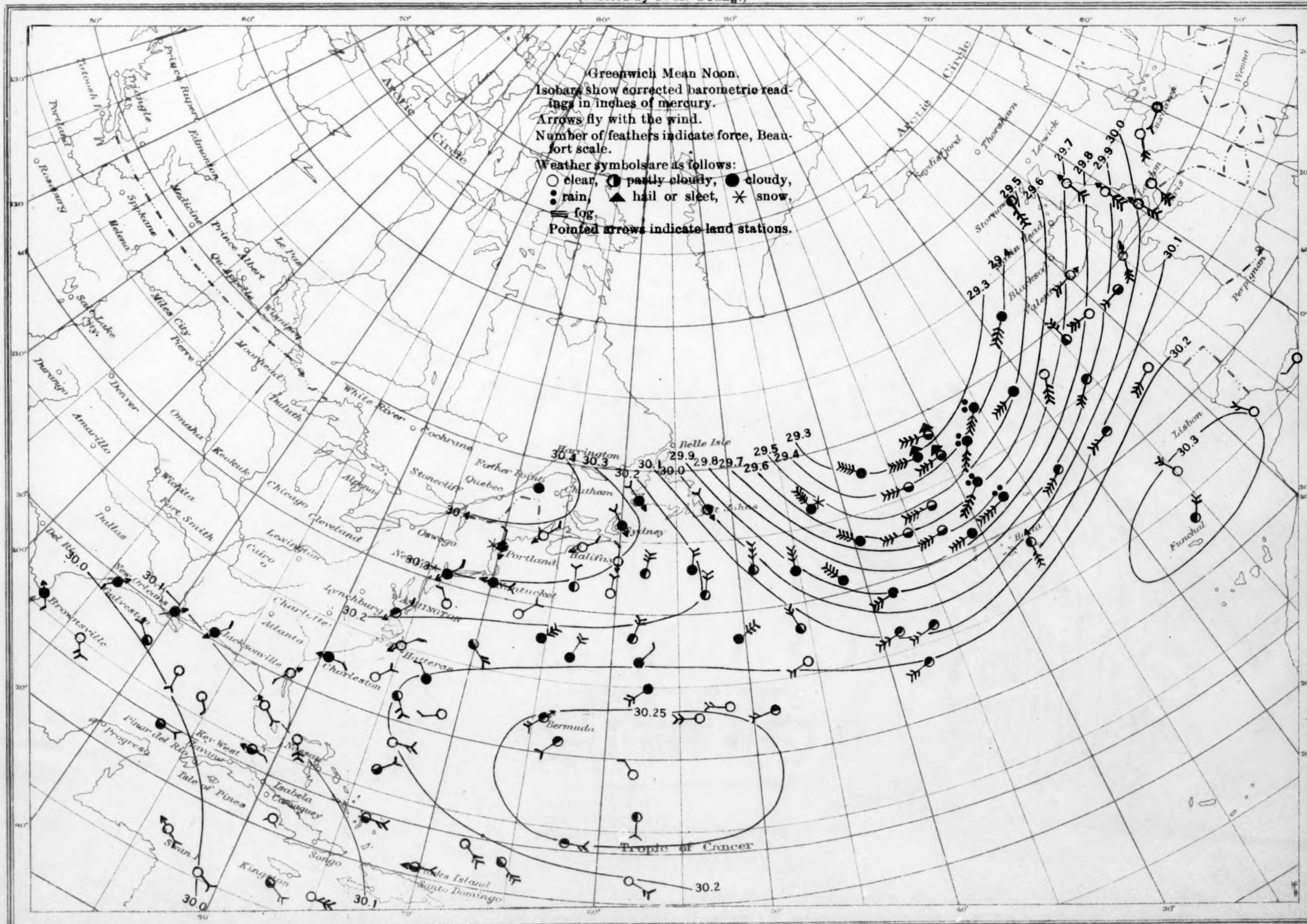


Chart XII. Weather Map of North Atlantic Ocean, March 15, 1921.
(Plotted by F. A. Young.)

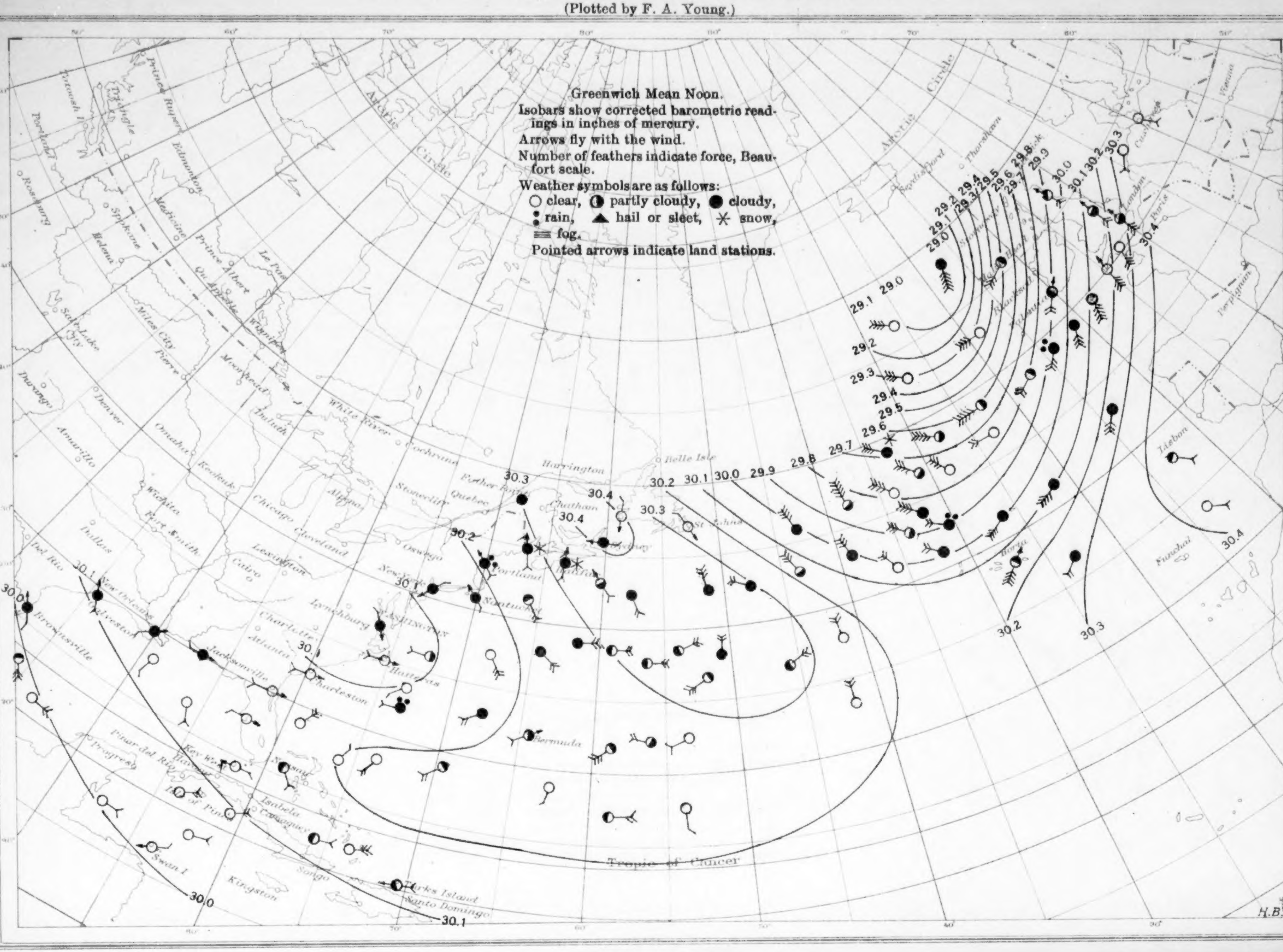
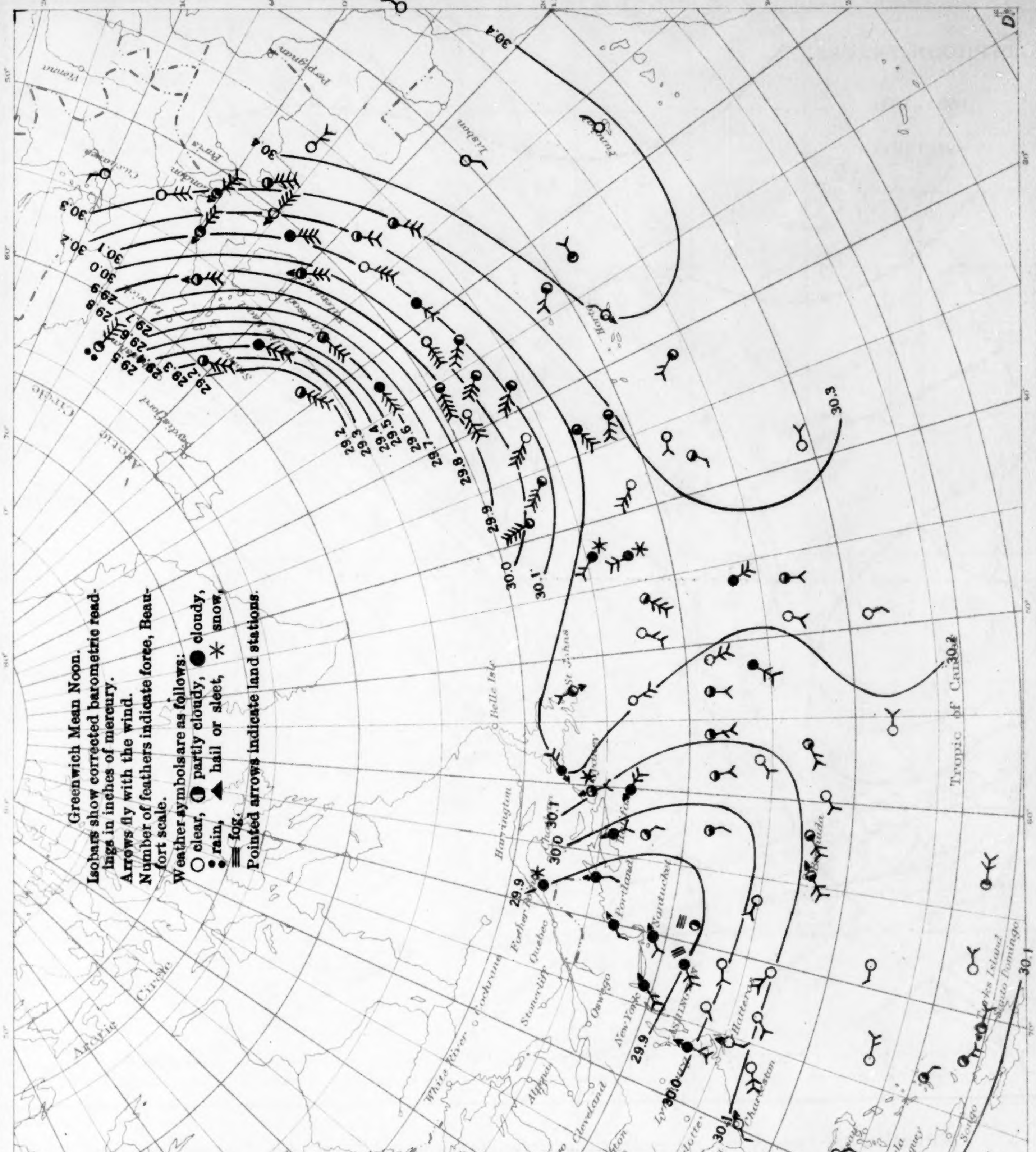
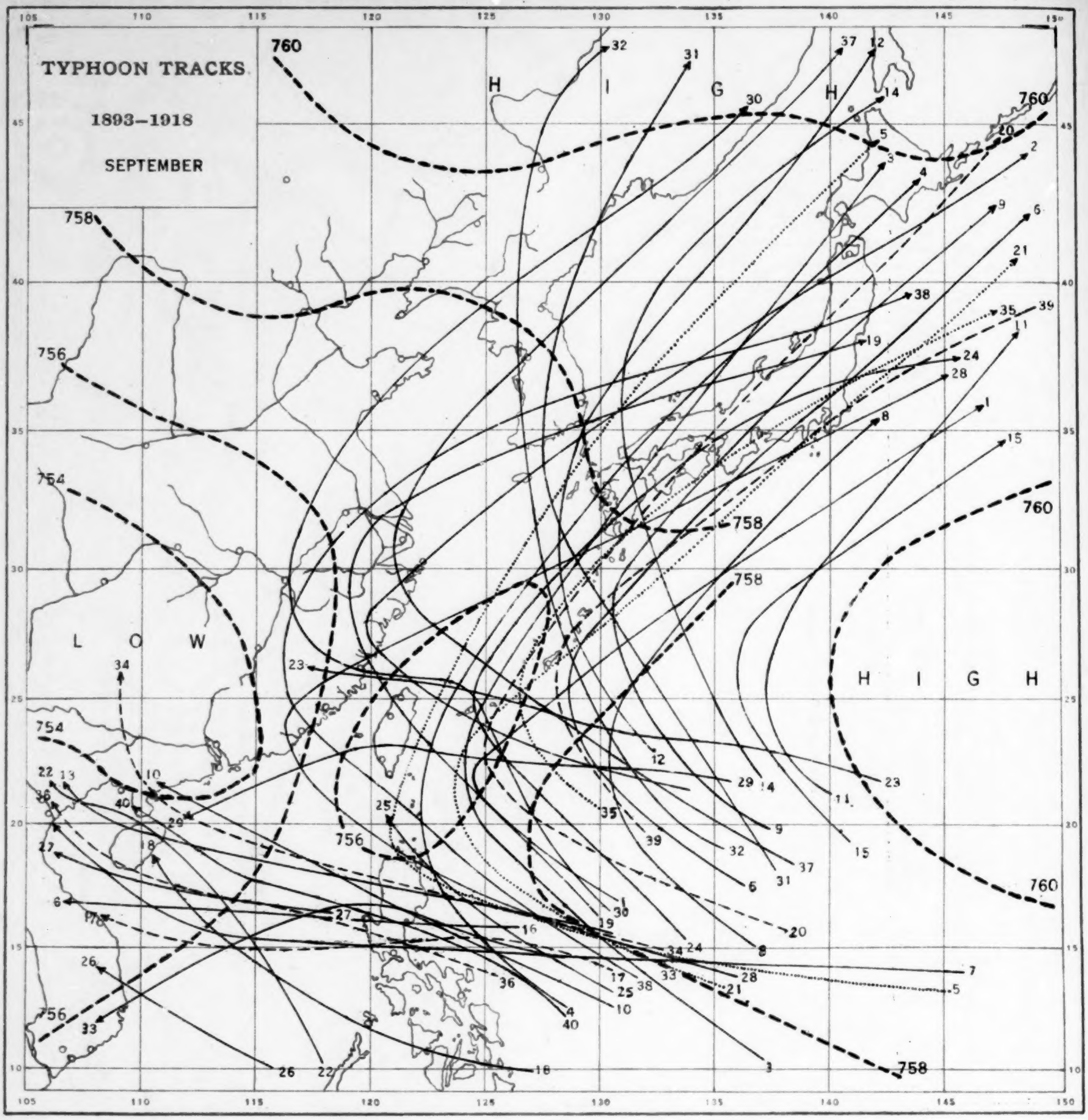


Chart XIII. Weather Map of North Atlantic Ocean, March 16, 1921.

Chart XIII. Weather Map of North Atlantic Ocean, March 16, 1921.
(Plotted by F. A. Young.)



TYPHOONS IN THE FAR EAST DURING 26 YEARS.

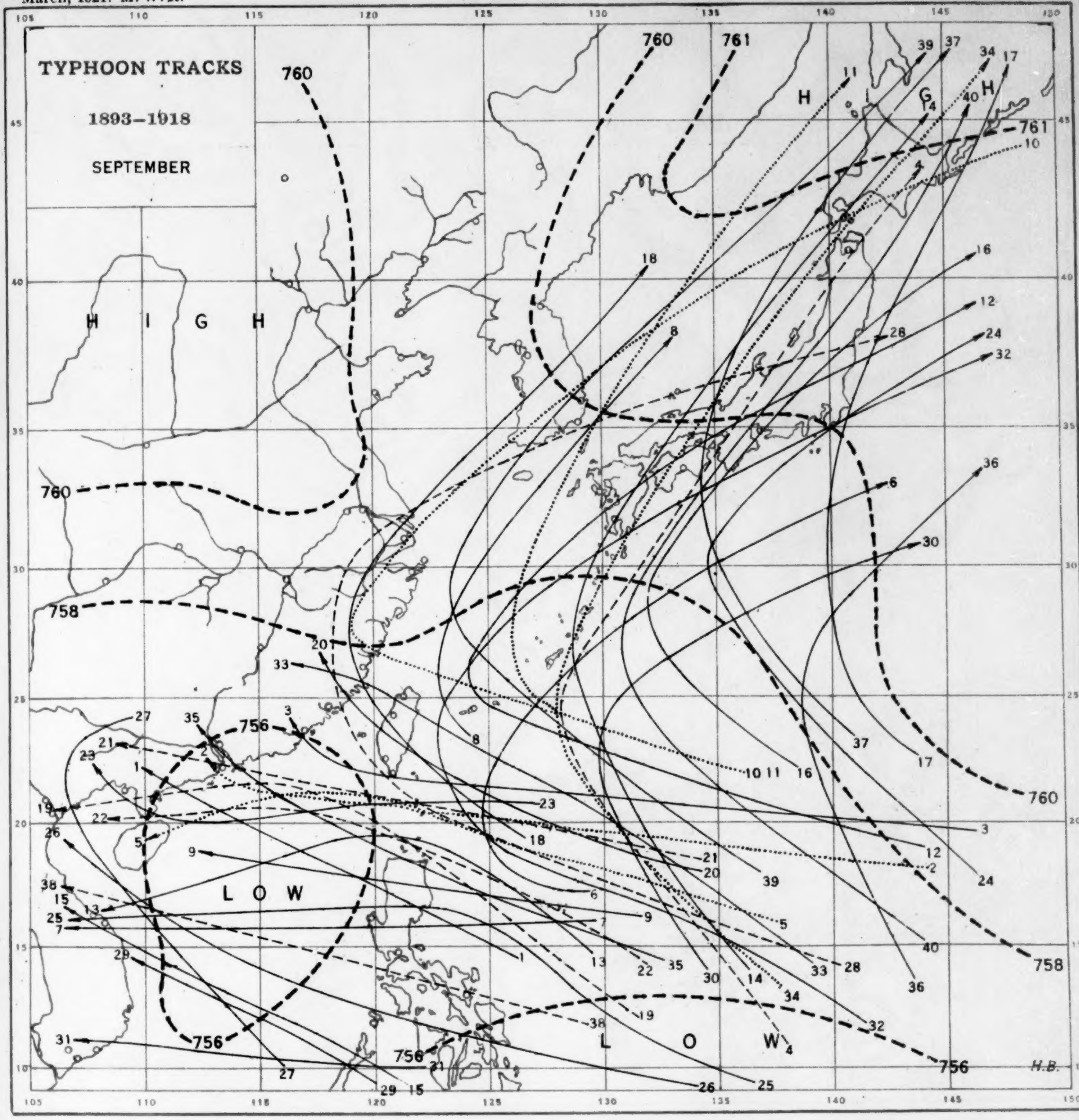


SEPTEMBER.—*Three charts: 109 tracks; the maximum of typhoons, a little more than 4 instances every year.*

First decade: 1-10.—40 tracks.—During these ten days the typhoons are more numerous than the whole of June. However the presence of the Asiatic maximum makes itself felt more and more; five storms only have crossed the Yellow Sea and the Formosa Strait becomes less dangerous by degrees. At the same time the two extreme edges of the *fan* of tracks extend themselves on both sides and show an increasing density of trajectories. On the SW side, the centres, advancing straight towards NW or WNW, rush in increasing numbers towards Tongking and Annam, and the dangerous zone gains ground as far as Palawan and the coast of Cochin-China. In the East, the season is in full swing across Japan and down to the Bonin group. A few cyclones continue to visit the N of Formosa and come to recurve inland near the mouth of the Yangtze.

The apex or turning point of the curves is gradually going down southwards, and the movement occurs frequently, to the SE of the Loochoos and the E of the Bashi Channel, between the 122nd and the 130th meridians. The handle of the *fan*, passes close to the eastern coast of Luzon, and not a few centres emanate from latitudes below 10°. The reader will remark at least two tracks running distinctly towards WSW on the China Sea. He will also note a kind of parallelism between many *parabolas*, and the curve of the isobar 758^{mm} on the Pacific.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893–1918, by Louis Froc, S. J., Director Zi-ka-wei Observatory, Zi-ka-wei–Chang-hai, 1920.]

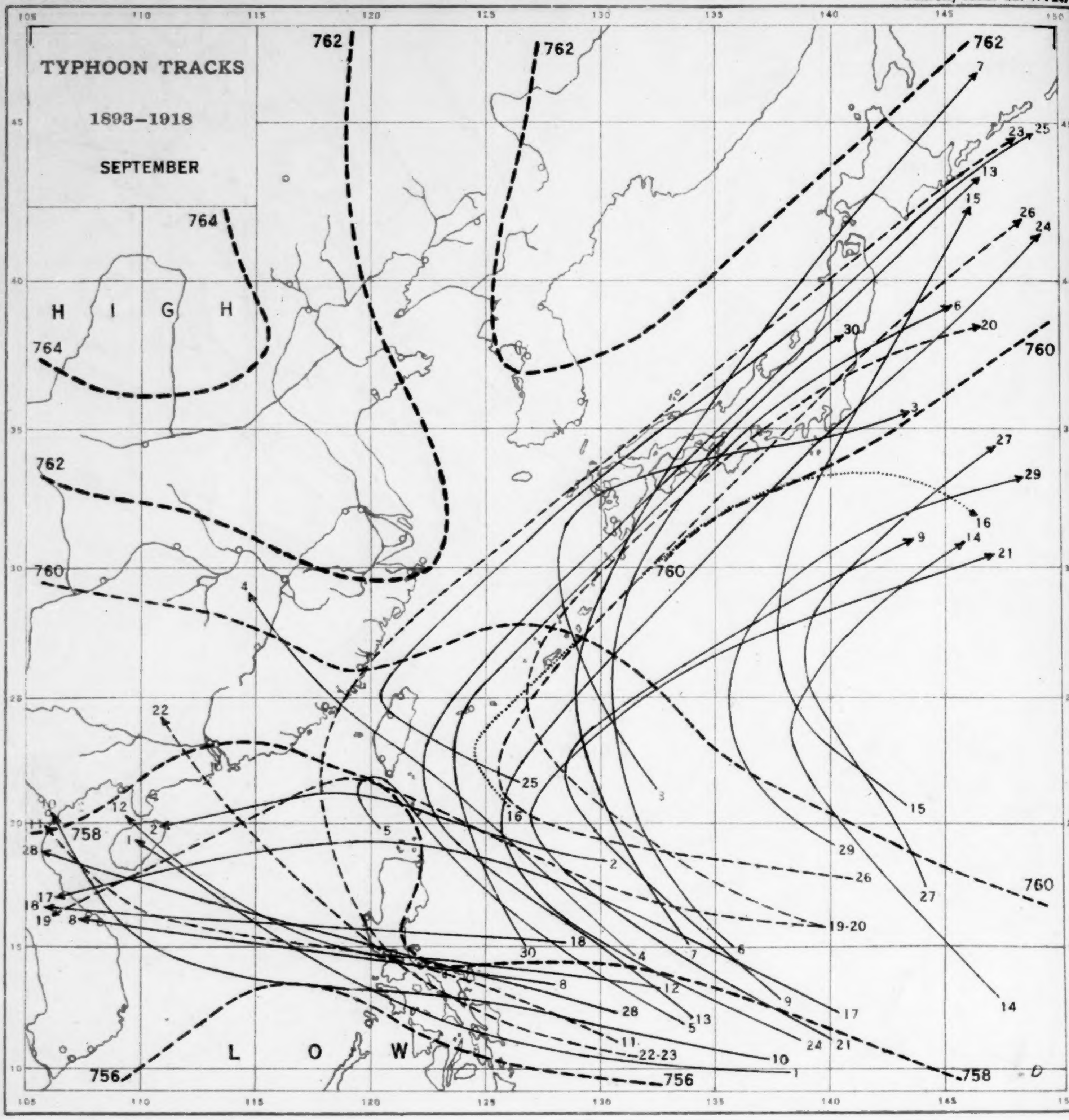


SEPTEMBER.—*Three charts: 109 tracks; the maximum of typhoons, a little more than 4 instances every year.*

Second decade: 11-20.—40 tracks.—The storms are still more driven both to East and West by the high pressures which are invading the Continent from the NW. No case has been observed, during the 26 years, to the North of a line passing through Chemulpo and the mouth of the Hwangho in Kiangsu. A few ones are still seen on the southern part of the Yellow Sea and in the Formosa Strait, the last ones nearly always bending when they reach the Chinese coast, and coming to pass on the mouth of the Yangtze. But at the same time there is an increasing intensity of cyclones on the whole of the China Sea which becomes full of danger as far as Cape St. James; the Paracels are threatened in a peculiar manner: it is also the season of the Kwangtung typhoons. At least 3 storms have recurved towards WSW to the S of the Pratas.

The advance of the continental maximum during the same period deserves notice: the isobaric line 760^{mm} approaches, like a spur, in the Yangtze Valley, as far as the mouth of the river; the low area, shown in the preceding maps, to the N. of Tongking has disappeared, while a distinct depression was taking shape, on the whole N. of the China Sea, between Hongkong and the 10th parallel.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893–1918, by Louis Froc, S. J., Director, Zi-ka-wei Observatory, Zi-ka-wei–Chang-hai, 1920.]



SEPTEMBER.—*Three charts: 109 tracks; the maximum of typhoons, a little more than 4 instances every year.*

Third decade: 21-30.—29 tracks.—The rent in the central part of the bundle or *fan* of storms is steadily progressing and broadening. Only two trajectories have ploughed their way across the Eastern Sea from SW to NE, and no case is signalled to the N. of a line joining Wenchow to the SW end of Hokkaïdo, across the Korea Strait. Japan is still frequently run over from end to end, as well as the Bonin islands. The China Sea has become more calm, but for a short time, to the S of the 15th parallel, while the N part of it is still freely opened to the incursions of the typhoons, which continue, in a few cases, to recurve to WSW between the Ballintang Channel and the coast of Annam.

The birth place of the storms continues to retire southwards, between the Carolines and Mindanao. The recurving points (*apex*) rather dispersed during the beginning of the month, come close together, to the E of the Bashi and Ballintang Channels, not far from the 20th parallel; a few ones are rounding the Bonin group.

The spur of the high pressures, marked by the isobar 762mm envelops now the mouth of the Yangtze, and the local minimum of S. China has disappeared. The few tracks that reach our coasts do not go very far inland, the low centres being soon filled up by the high pressures of the Continent.

[Reproduced from Atlas of the Tracks of 620 Typhoons, 1893–1918, by Louis Froc, S. J., Director Zi-ka-wei Observatory. Zi-ka-wei–Chang-bai. 1920.]

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MARCH, 1921.

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CORRIGENDA.

Review, February, 1921:
- Page 78, figure 3, the diagram over legend 3 belongs over legend 4.
- Page 78, figure 4, the diagram over legend 4 belongs over legend 5.
- Page 79, figure 5, the diagram over legend 5 belongs over legend 3.